The Economics of Enhanced Geothermal Systems

with an Energy-Economic Model of West Virginia University Case Study

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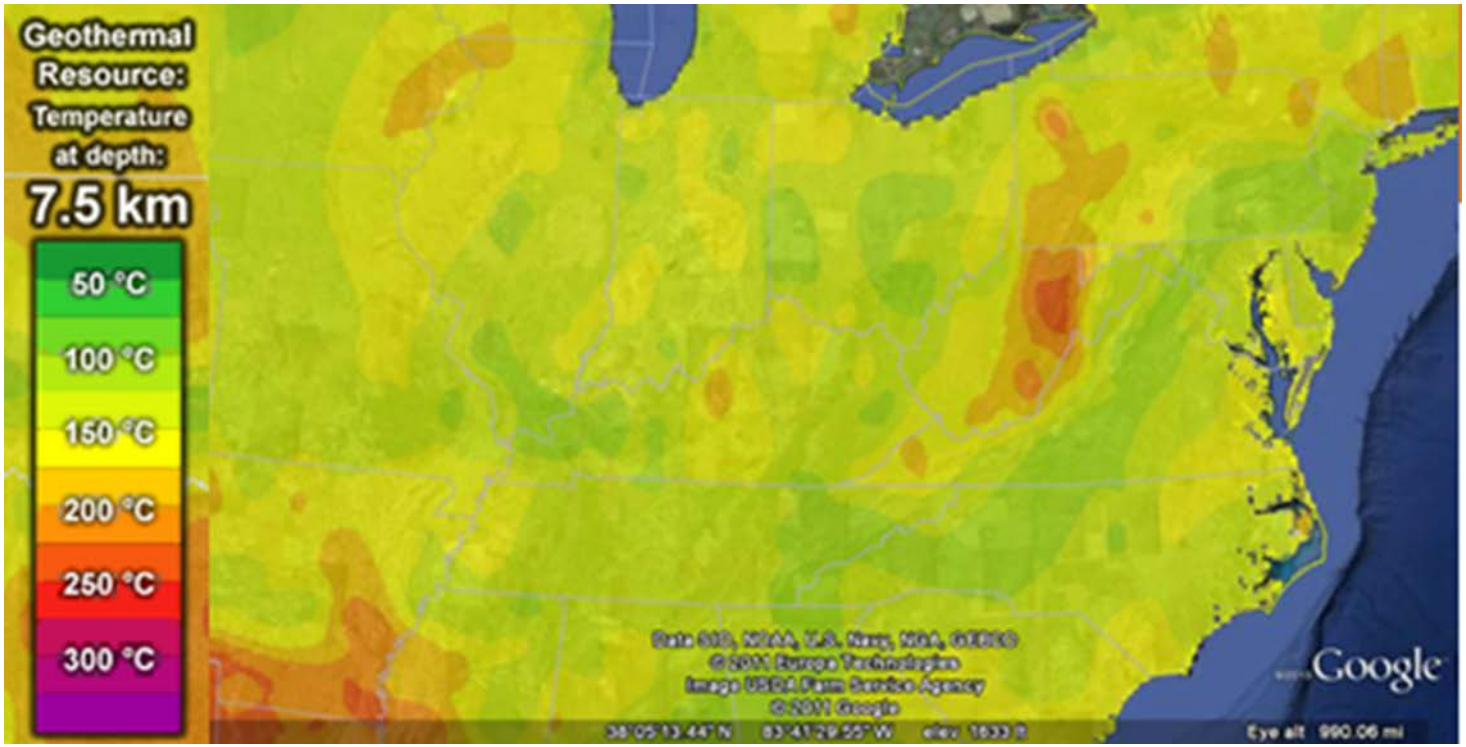

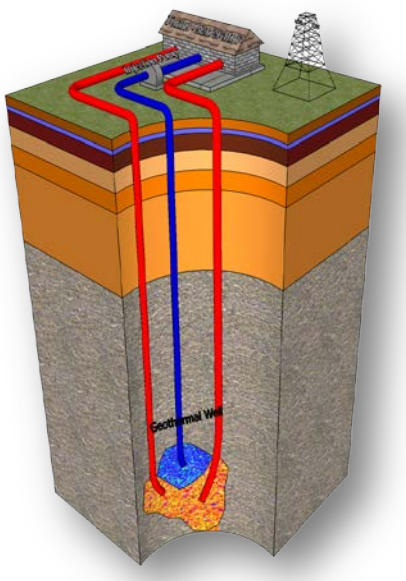

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West Virginia Is a Geothermal Hot Spot

by Eli Kintisch on 4 October 2010, 5:02 PM | Permanent Link | 5 Comments

Researchers have uncovered the largest geothermal hot spot in the eastern United States. According to a unique collaboration between Google and academic geologists, West Virginia sits atop several hot patches of Earth, some as warm as 200°C and as shallow as 5 kilometers. If engineers are able to tap the heat, the state could become a producer of green energy for the region.

ENLARGE IMAGE

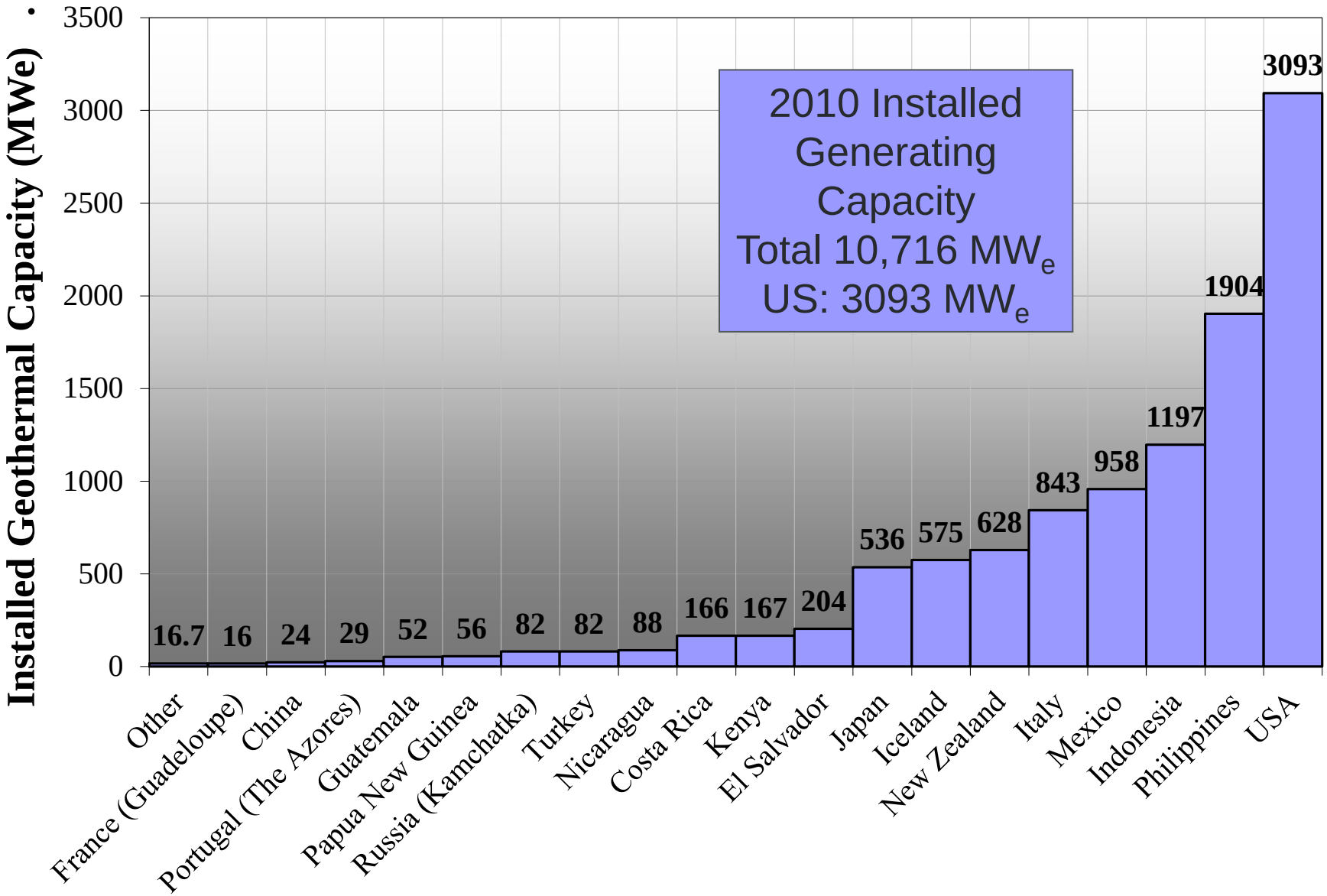
Hot or not? A new map of underground temperatures suggests that West Virginia has great potential for geothermal energy.

Credit: Source: Southern Methodist University and Google.org

In 2004, researchers at Southern Methodist University (SMU) in Dallas, Texas, and colleagues created the *Geothermal Map of North America*. The map charted the potential for geothermal energy nationwide. Two years ago Google.org, the philanthropic arm of the search engine giant, hired the SMU scientists to update the map.

The group analyzed temperature data from oil and gas firms that no one had bothered to map. Those data were collected via single thermometer readings on the end of drilling equipment, but the readings were artificially low

Geothermal Energy Today – Electricity Production



Data: International Geothermal Association

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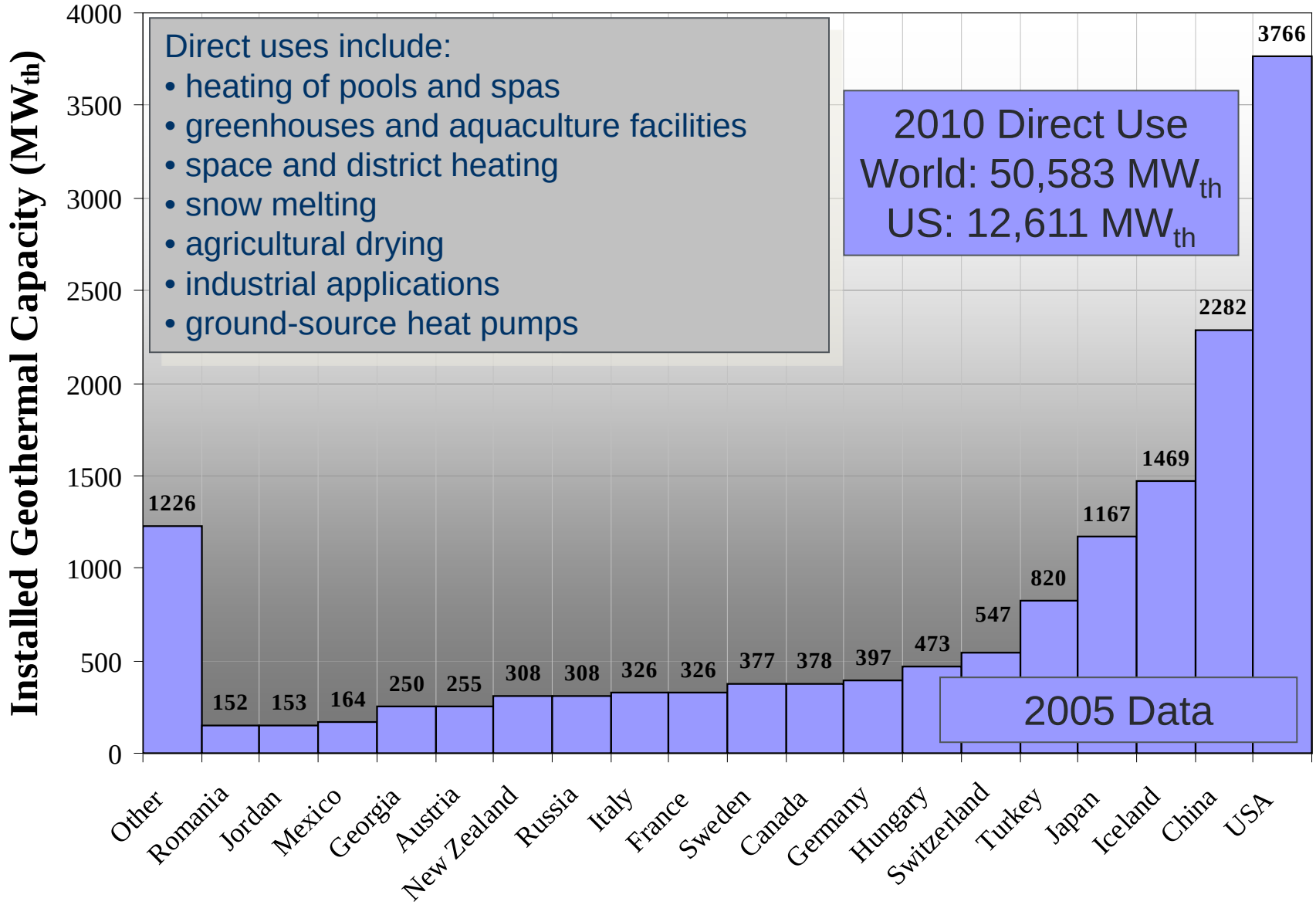
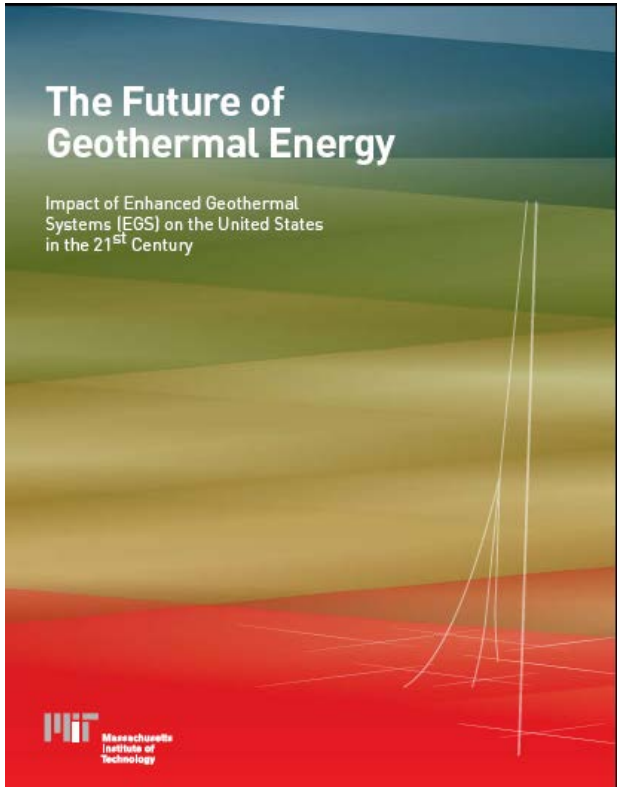
Direct Use Geothermal Worldwide



The Future of Geothermal Energy

Energy Recovery from Enhanced/Engineered Geothermal Systems (EGS) – Assessment of Impact for the US by 2050



An MIT– led study by an 18- member international panel

Primary goal – to provide an independent and comprehensive evaluation of EGS as a major US primary energy supplier

Secondary goal – to provide a framework for informing policy makers of what R&D support and policies are needed for EGS to have a major impact

Multidisciplinary EGS Assessment Team

Panel Members

- Jefferson Tester, chair, Cornell, energy systems specialist, chemical engineer
- Brian Anderson, West Virginia University, chemical engineer
- Anthony S. Batchelor, GeoScience, Ltd, rock mechanics and geotechical engineer
- David Blackwell, Southern Methodist University, geophysicist
- Ronald DiPippo, power conversion consultant, mechanical engineer
- Elisabeth Drake, MIT, energy systems specialist, chemical engineer
- John Garnish, physical chemist, EU Energy Commission (retired)
- Bill Livesay, Drilling engineer and consultant
- Michal Moore, University of Calgary, resource economist
- Kenneth Nichols, Barber-Nichols, CEO (retired), power conversion specialist
- Susan Petty, AltaRock Energy, Inc, President
- Nafi Toksoz, MIT, seismologist
- Ralph Veatch, reservoir stimulation consultant, petroleum engineer

Associate Panel Members

- Roy Baria, former Project Director of the EU EGS Soultz Project , geophysicist
- Enda Murphy and Chad Augustine, MIT chemical engineering research staff
- Maria Richards and Petru Negraru, geophysists, SMU Research Staff

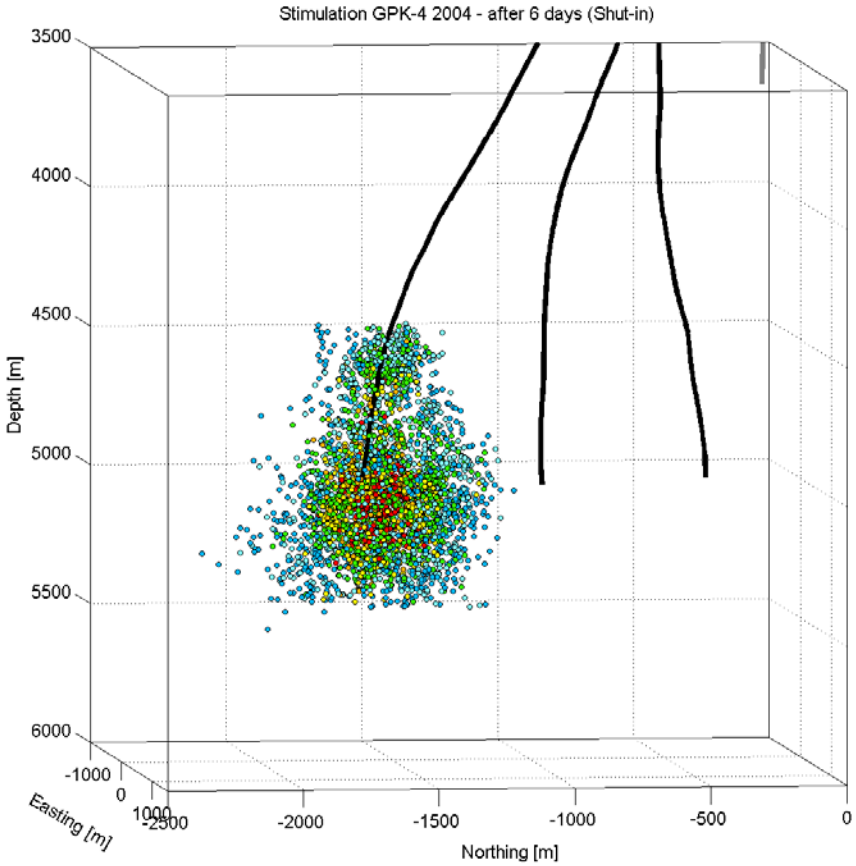
Support Staff

- Gwen Wilcox, MIT

Key technical challenge for EGS is developing stimulation methods to create a well-connected reservoir

Connectivity is achieved between injection and production wells by Hydraulic pressurization to re-open existing, sealed fractures and to create new ones

Goal is to engineer an inter-connected well system that emulates the productivity of a good hydrothermal reservoir in terms of heat production rate and lifetime



"snap shot" of microseismic events during hydraulic fracturing at Soultz from Roy Baria

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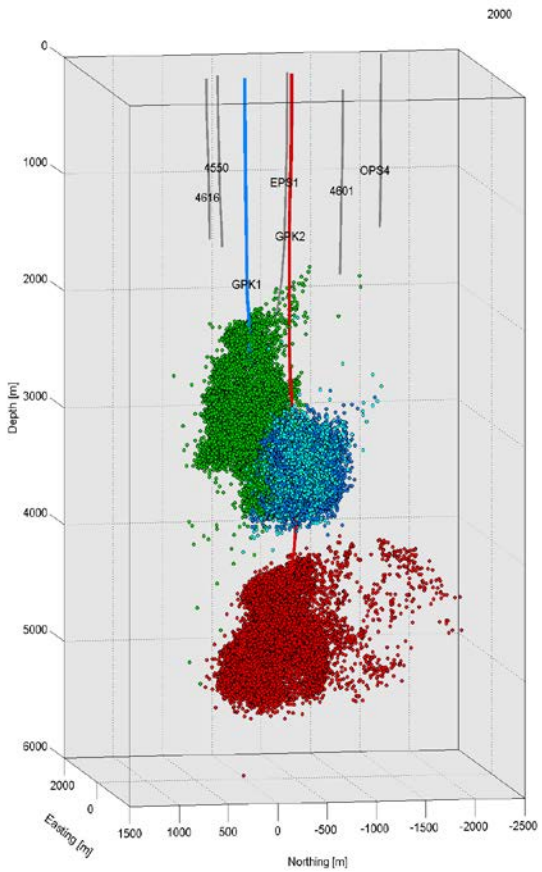
Although much has been accomplished there are a few things left to do



1. Commercial level of fluid production with an acceptable flow impedance thru the reservoir
2. Establish modularity and repeatability of the technology over a range of US sites
3. Lower development costs for low grade EGS systems

Our analysis evaluated the lowering of risks and costs as a result of investments in research, development and demonstration

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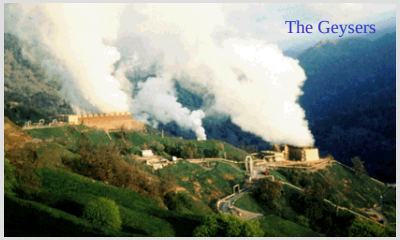
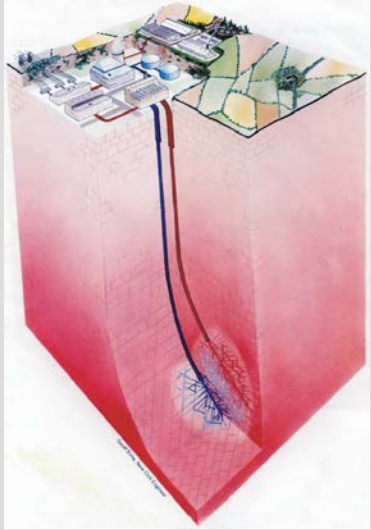
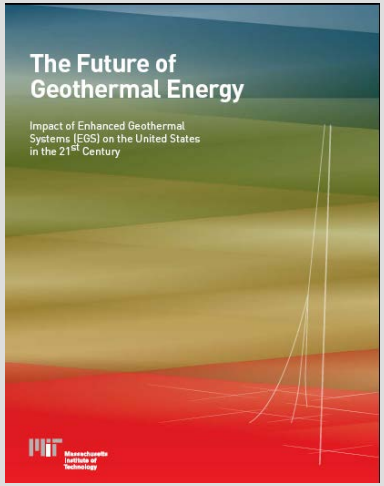
U.S. Geothermal Growth

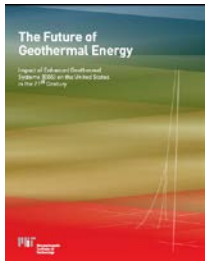
- **Hydrothermal Systems**
  - Western Governor's Association estimates
    - 13,000 MW_e in 10-20 yr
    - 5,600 MW_e in 5-10 yr
  - Existing technology
  - US Potential > 15,000 MW_e
  - World Potential 35,000–72,000 MW_e



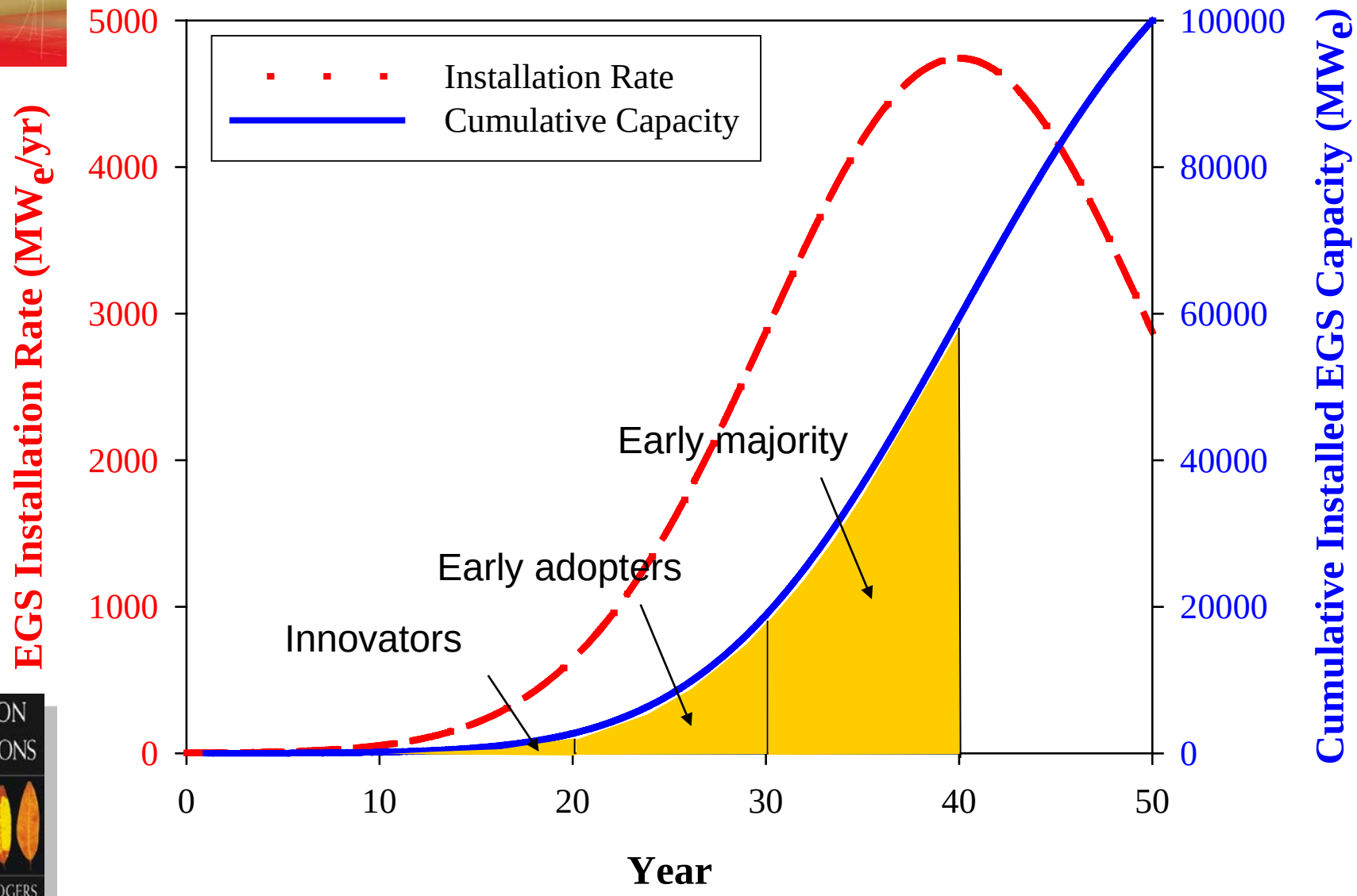
- **Engineered/Enhanced Geothermal Systems (EGS)**
  - Extremely large potential
  - US > 100,000 MW_e

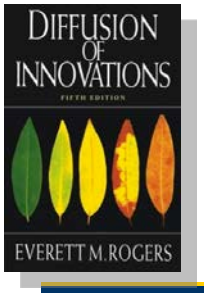






Diffusion of Alternative Energy Innovation

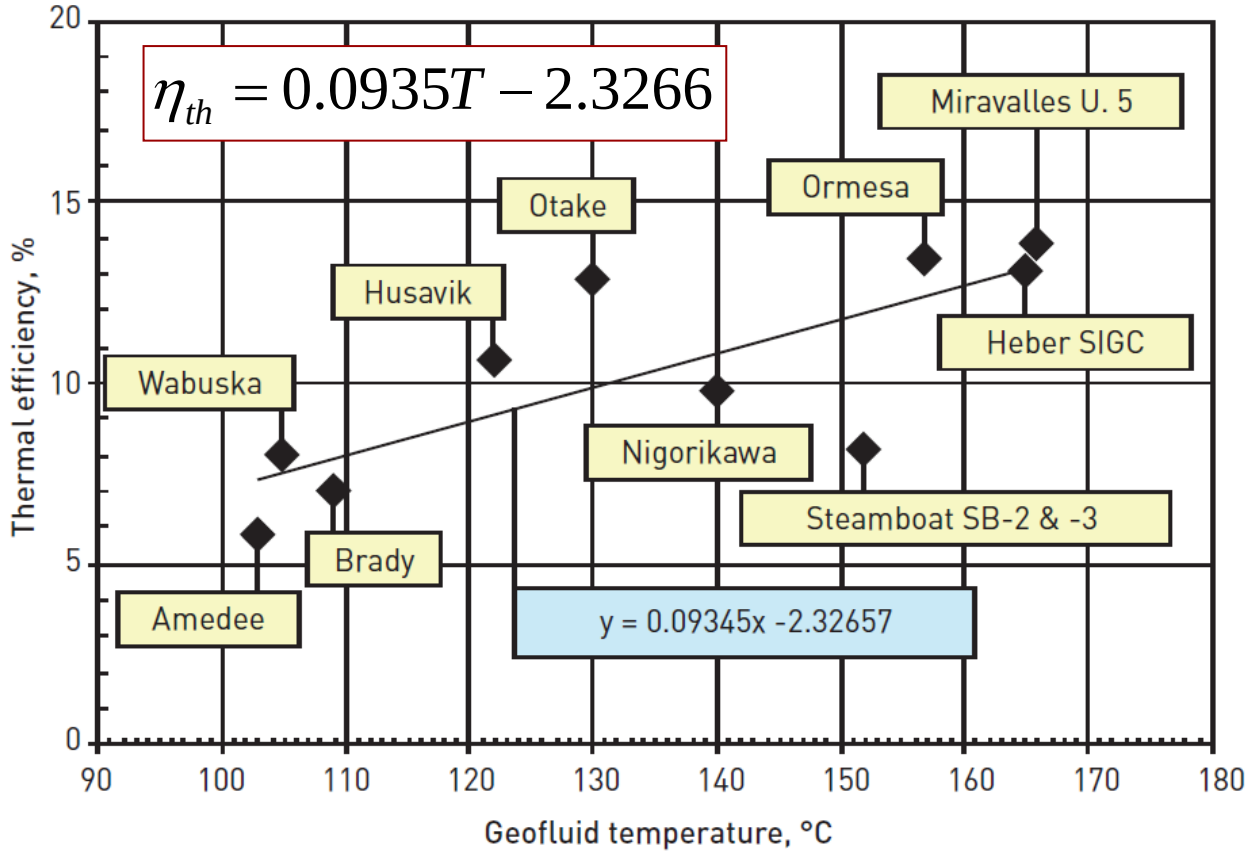




Tester, Anderson et al., *The Future of Geothermal Energy*, MIT Press, Cambridge (2006)

Surface Plant Cost Modeling

- **Ways to estimate cost**
  - Correlation-based cost models
  - Currently developing estimates of surface equipment costs
    - Radiators, heat exchangers, pumps, etc.
  - Additionally, we are examining direct use for biomass drying and integration into gasification and pyrolysis systems



Correlation of binary plant cycle thermal efficiency with geofluid temperature. Source: *The Future of Geothermal Energy*, 2006.

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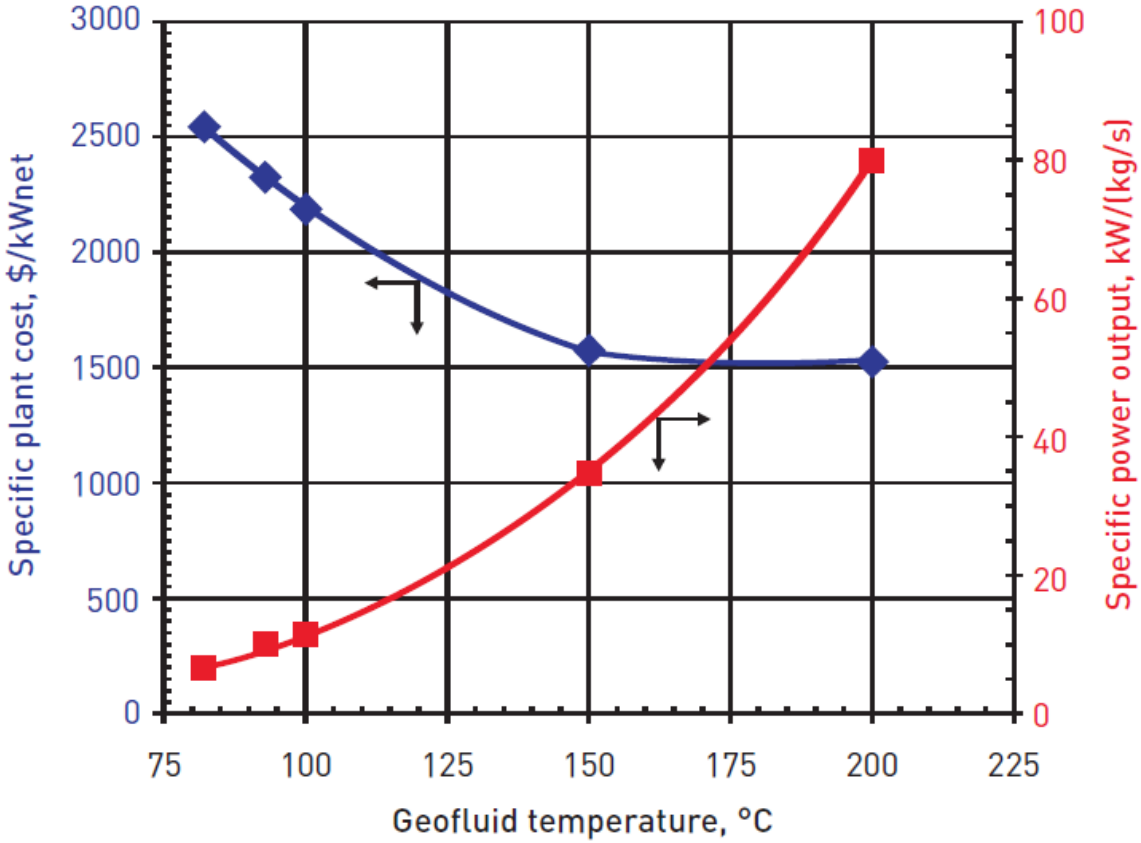


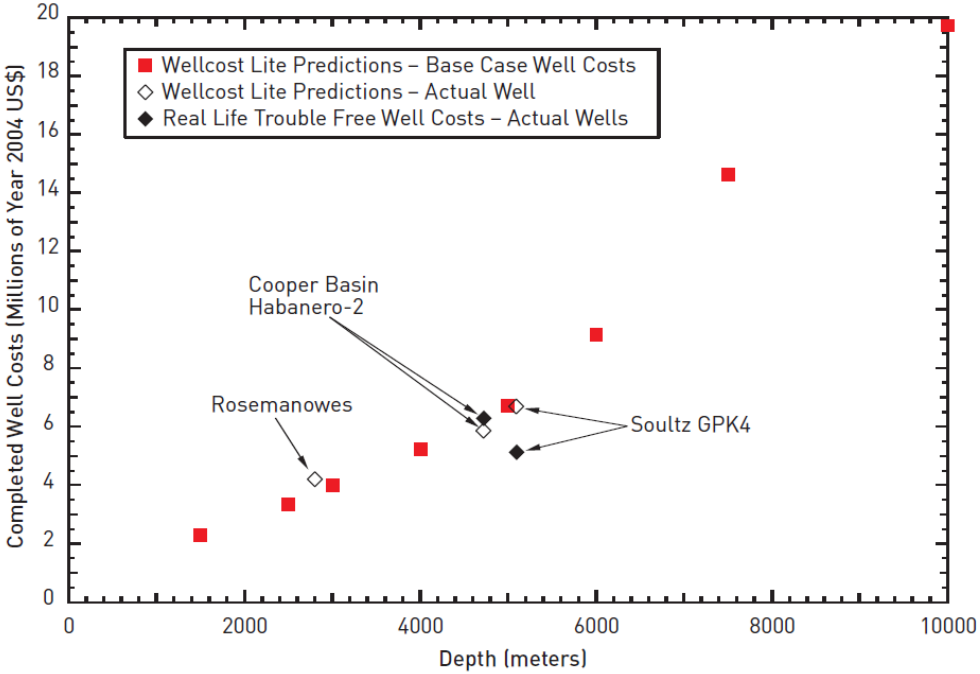
Cost and performance of 1 MW binary power plants as a function of geofluid temperature. Source: *The Future of Geothermal Energy*, 2006.

Drilling Cost Model

EGS well drilling-cost estimates from Wellcost Lite in 2004 U.S. $

Source: *The Future of Geothermal Energy*, 2006.

Shallow			Mid Range			Deep		
Depth, m (ft)	No. of Casing Strings	Cost, million $	Depth, m (ft)	No. of Casing Strings	Cost, million $	Depth, m (ft)	No. of Casing Strings	Cost, million $
1,500 (4,900)	4	2.3	4,000 (13,100)	4	5.2	6,000 (19,700)	5	9.7
2,500 (8,200)	4	3.4	5,000 (16,400)	4	7.0	6,000 (19,700)	6	12.3
3,000 (9,800)	4	4.0	5,000 (16,400)	5	8.3	7,500 (24,600)	6	14.4
						10,000 (32,800)	6	20.0



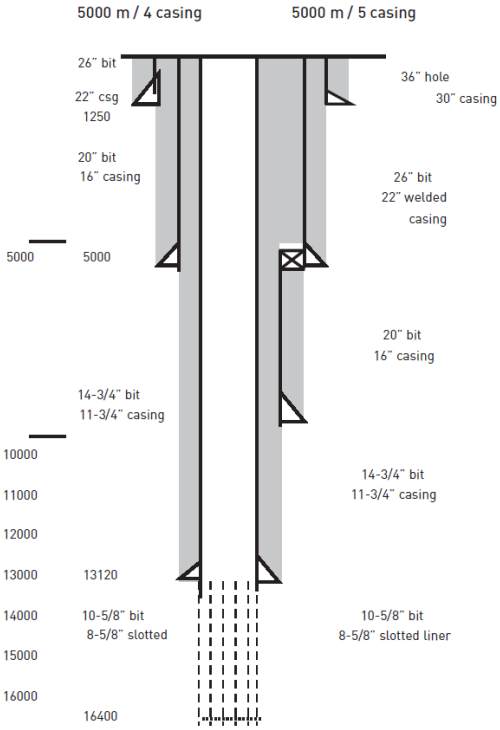
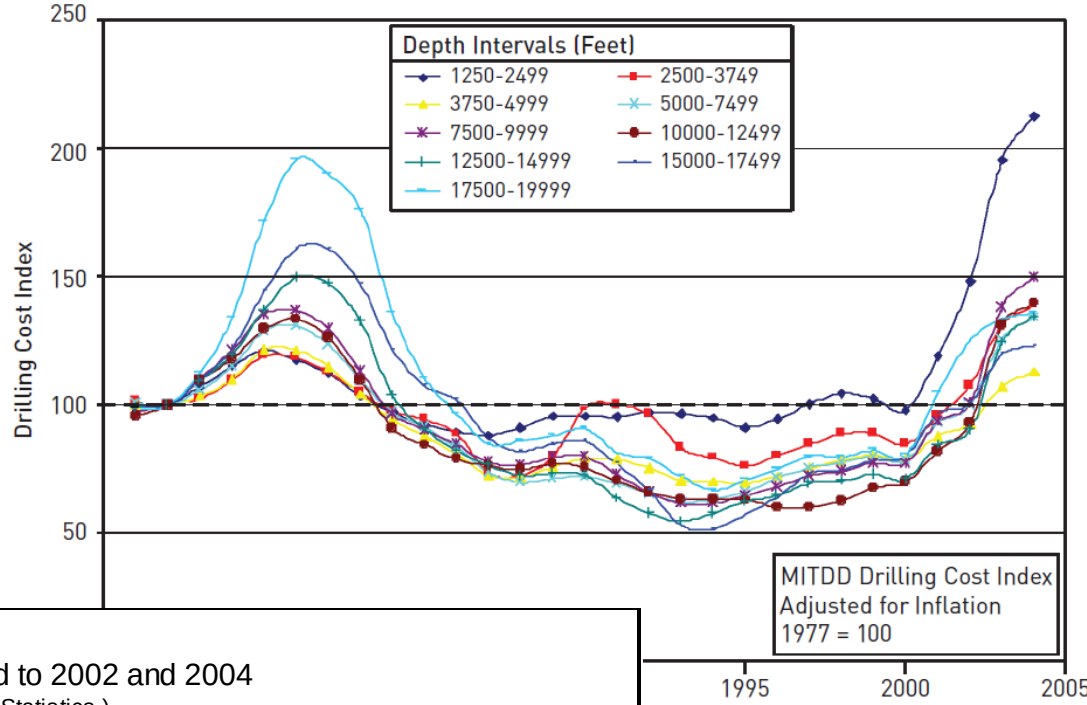


Figure 6.8 EGS well-cost predictions from the Wellcost Lite model and historical geothermal well costs, at various depths.

Drilling Cost Index

MITDD drilling cost index, adjusted for inflation to 2004 U.S. $.

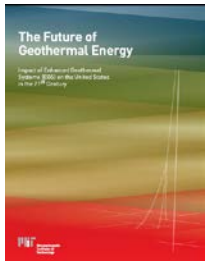
Source: *The Future of Geothermal Energy*, 2006.



GETEM Cost Indices

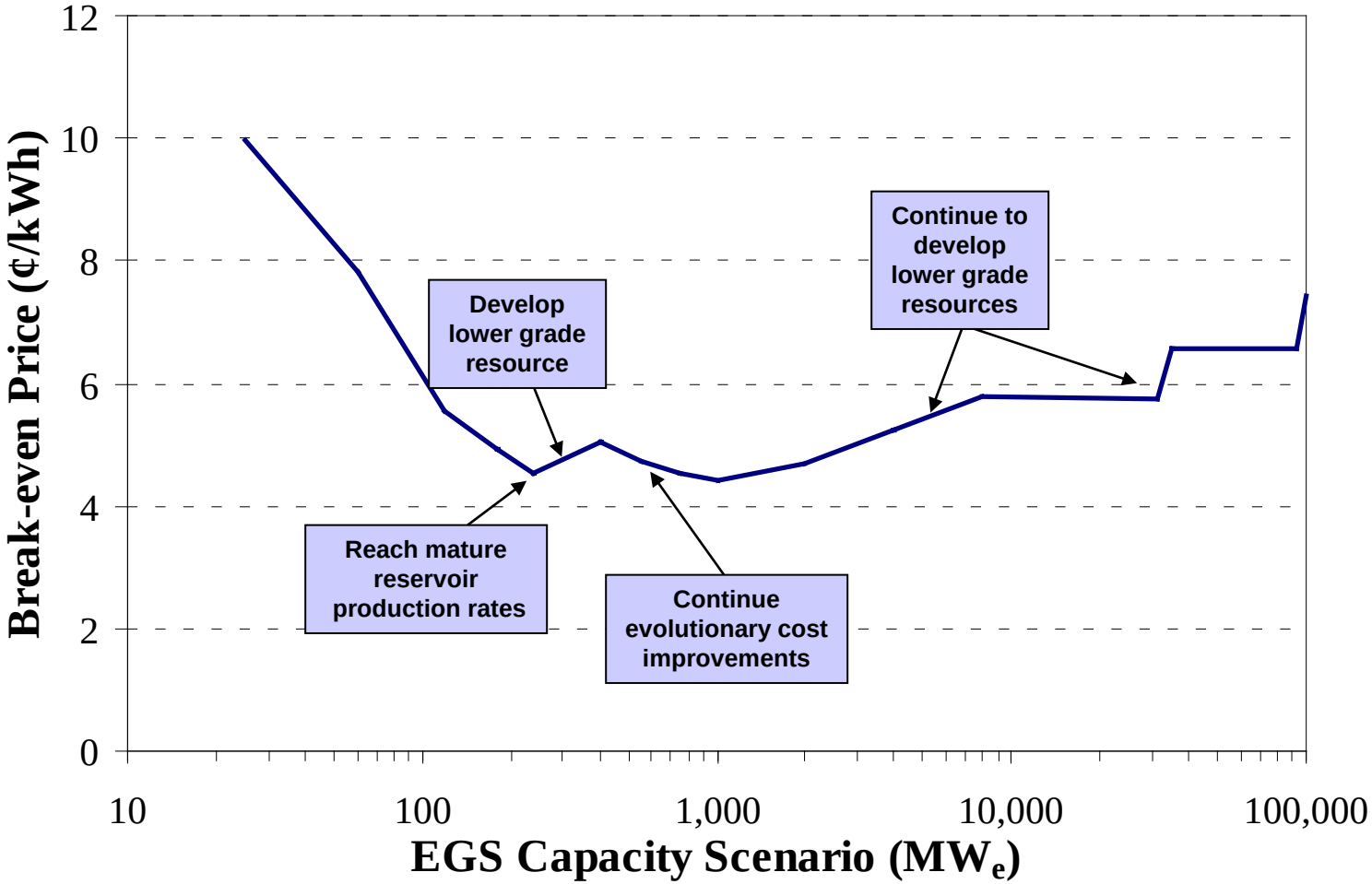
Table 1: Cost Indices - Normalized to 2002 and 2004
(Source US Bureau of Labor Statistics)

Year	Manufact Labor	Construct	Engineering	Steel	Pipe	Electrical	Turb-Gen	HX's	Pumps	Process Equi	Oil&Gas Well
1995	0.807	0.791	0.780	1.129	0.939	0.958	0.883	0.891	0.853	0.884	0.612
1996	0.834	0.817	0.811	1.103	0.964	0.961	0.896	0.920	0.872	0.907	0.625
1997	0.859	0.842	0.859	1.109	0.986	0.962	0.918	0.939	0.900	0.926	0.704
1998	0.880	0.873	0.889	1.074	0.978	0.965	0.935	0.957	0.924	0.942	0.757
1999	0.906	0.909	0.914	0.999	0.951	0.976	0.960	0.964	0.937	0.957	0.738
2000	0.937	0.933	0.954	1.022	0.984	1.000	0.969	0.973	0.950	0.968	0.793
2001	0.965	0.958	0.976	0.961	0.995	1.004	0.980	0.983	0.976	0.985	0.988
2002	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.934
2003	1.029	1.039	1.049	1.065	1.014	0.999	1.013	0.999	1.011	1.015	0.912
2004	1.056	1.067	1.082	1.423	1.219	1.042	1.019	1.066	1.040	1.078	1.000
2005	1.083	1.089	1.103	1.500	1.341	1.103	1.018	1.227	1.094	1.155	1.577
2006	1.099	1.129	1.136	1.635	1.414	1.203	1.050	1.333	1.142	1.223	2.356
2007	1.129	1.170	1.210	1.762	1.394	1.303	1.107	1.378	1.213	1.305	2.299
2008	1.160	1.222	1.275	2.160	1.500	1.475	1.245	1.438	1.278	1.383	2.339
2009	1.191	1.274	1.325	1.612	1.569	1.391	1.353	1.412	1.314	1.403	2.031



Supply Curve for the US EGS resource

MIT EGS model predictions reaching mature reservoir technology at 80 kg/s per production well



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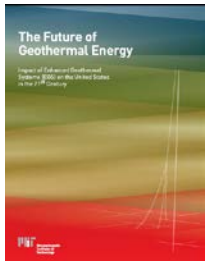
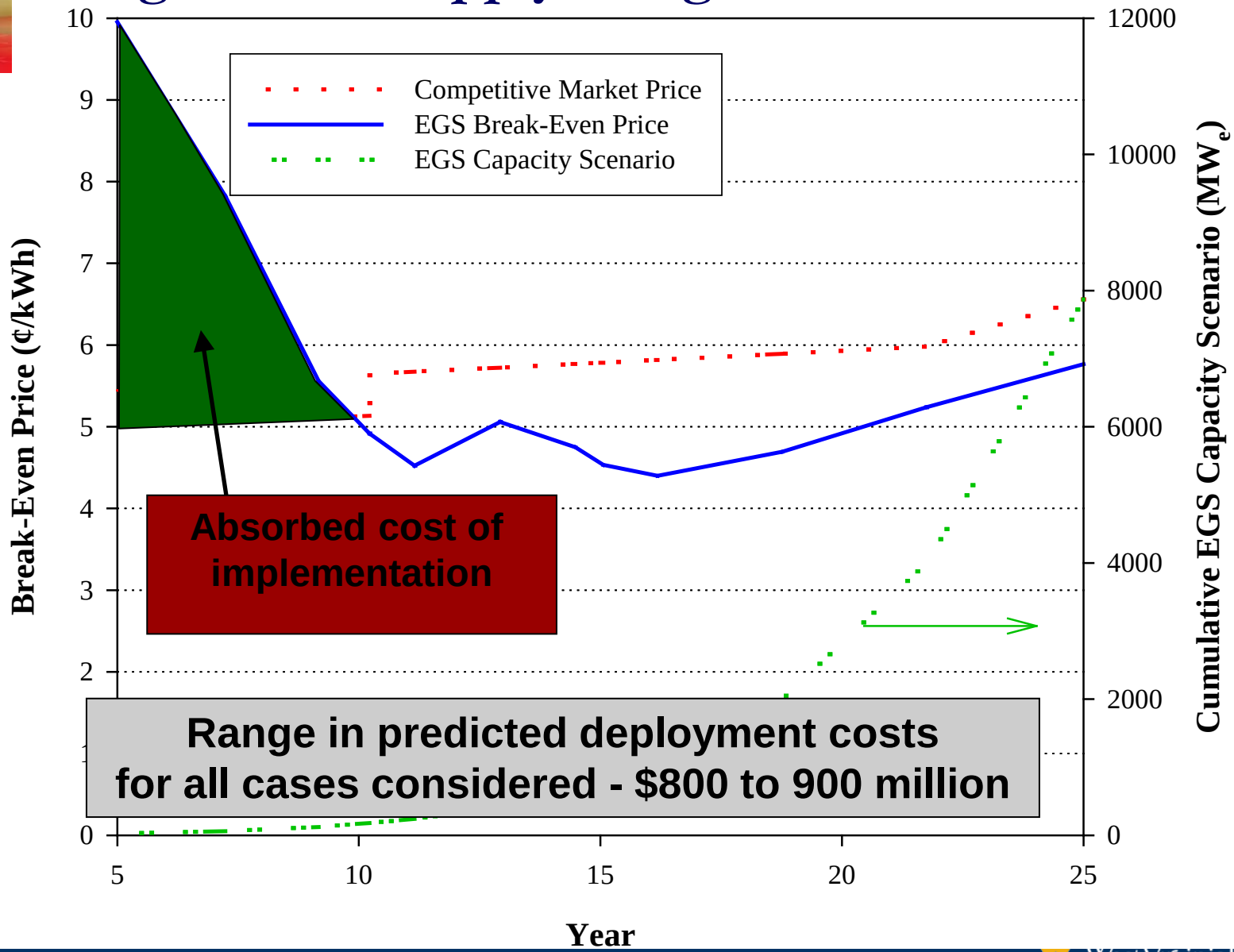
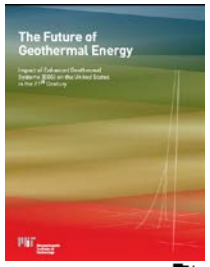
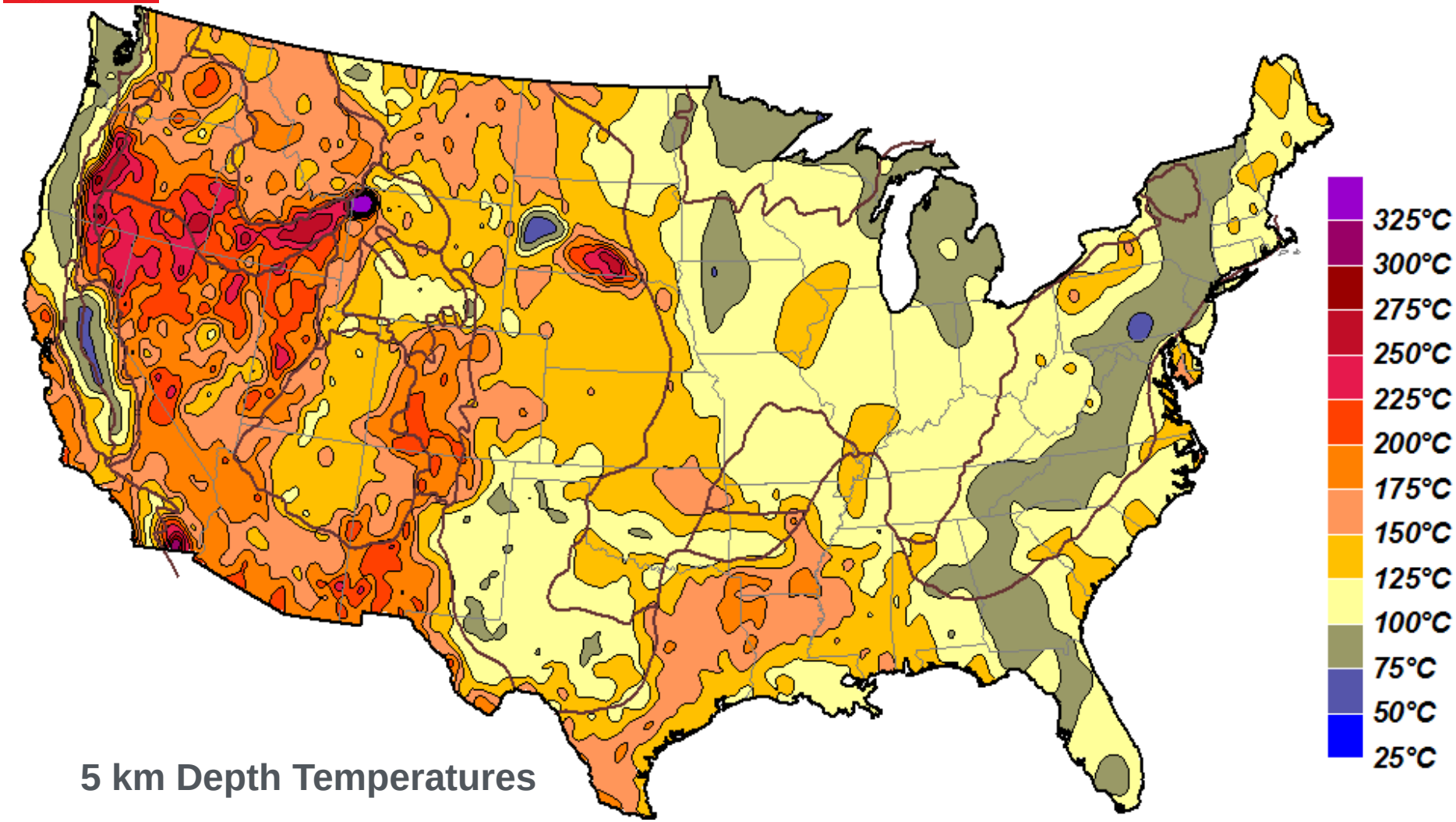


Predicted levelized break-even price (LEC) and growth in supply using MIT EGS model





Geothermal Temperatures – 5 km

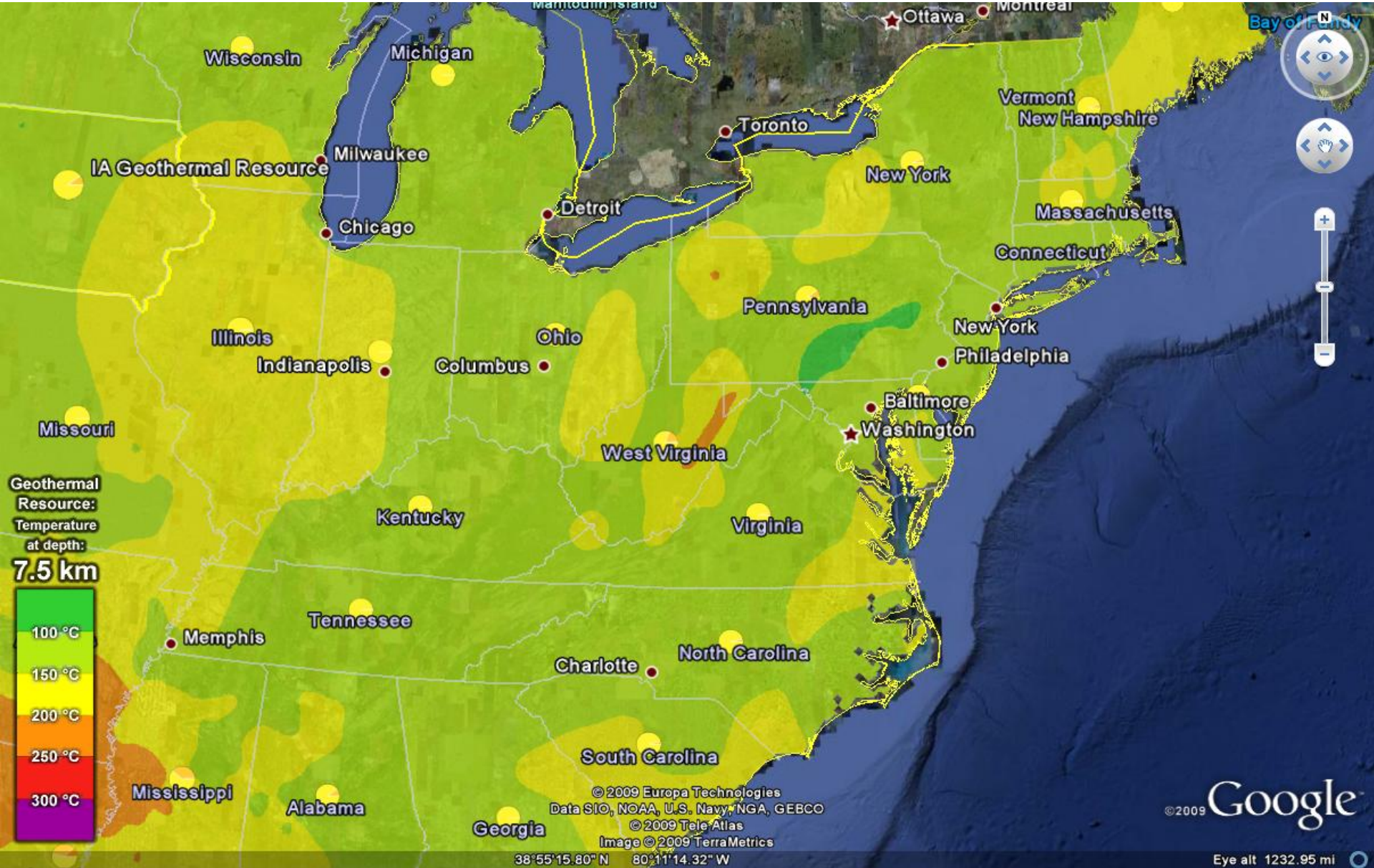


5 km Depth Temperatures

Tester, Anderson et al., *The Future of Geothermal Energy,* MIT Press, Cambridge (2006)

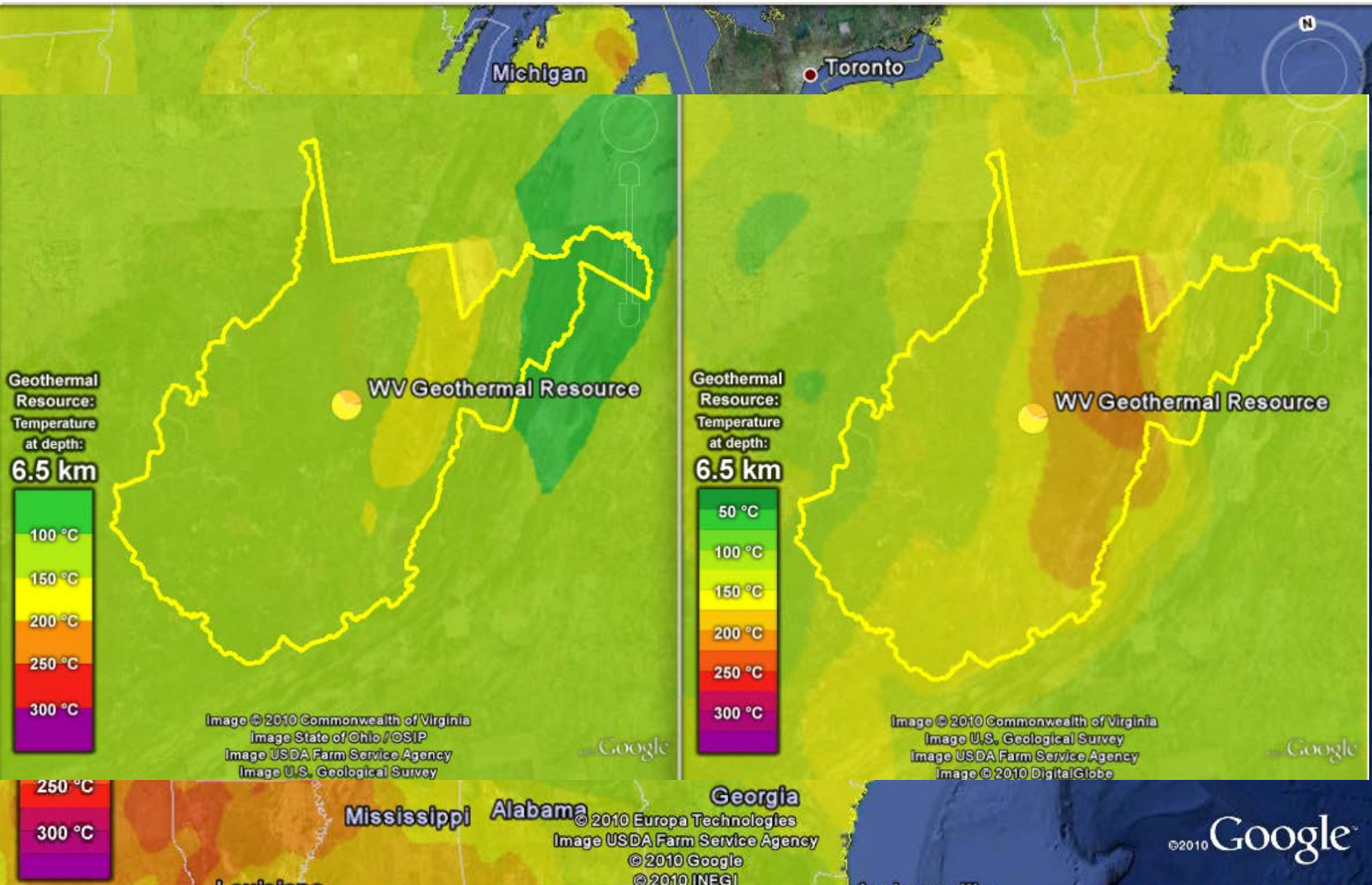
Geothermal in WV

Based on 2006 MIT Future of Geothermal Energy

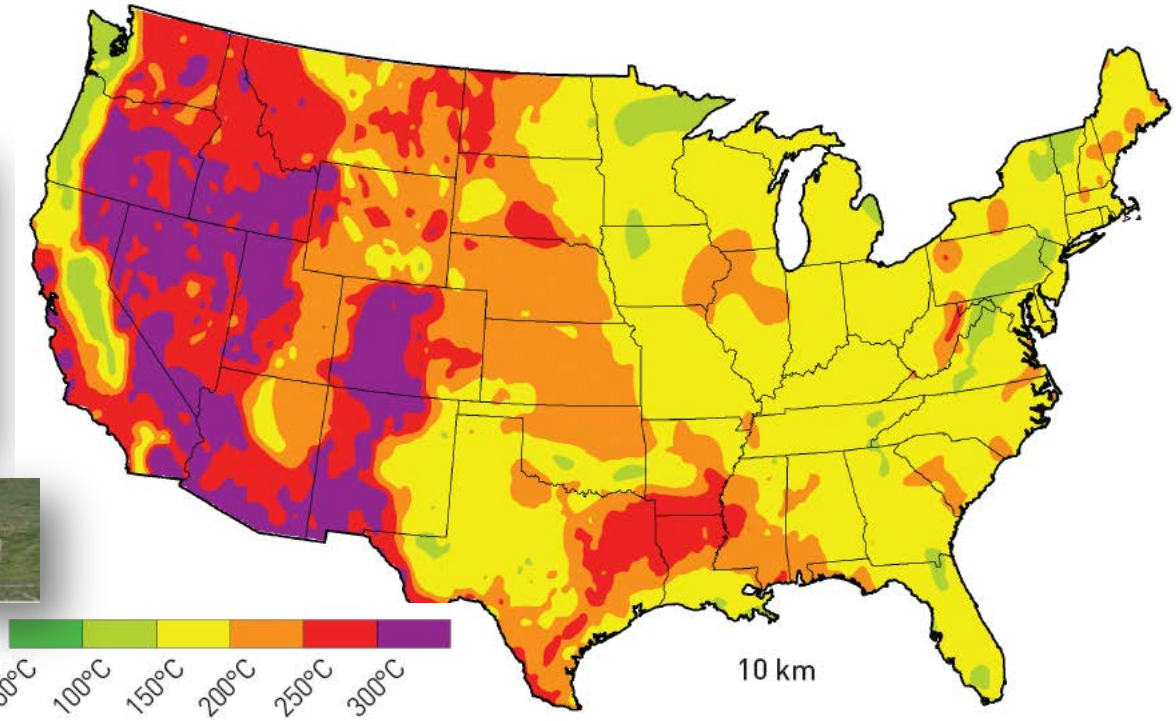


Geothermal in WV

Based on 2010 SMU Work



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



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Iowa State University

Cornell University

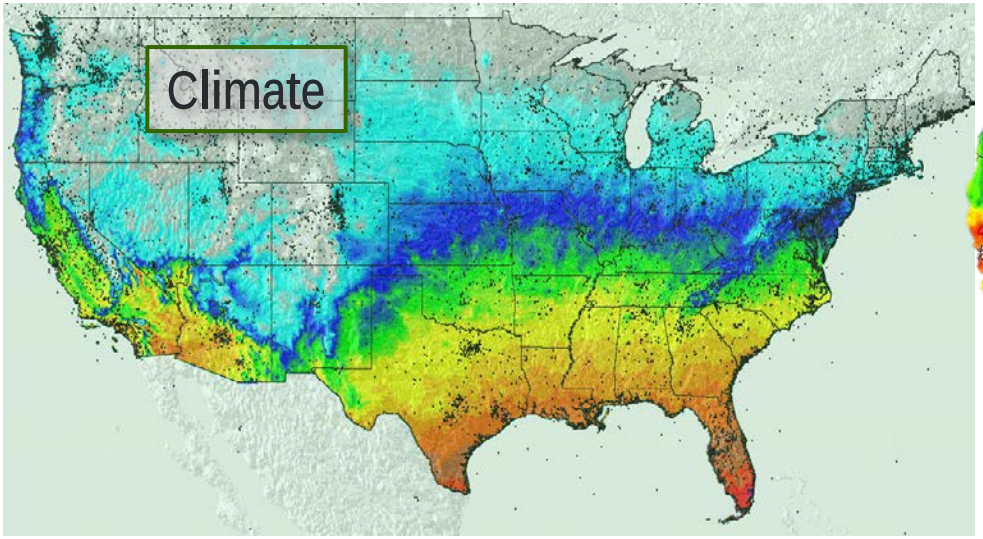
Analysis of Low-Temperature Utilization of Geothermal Resources

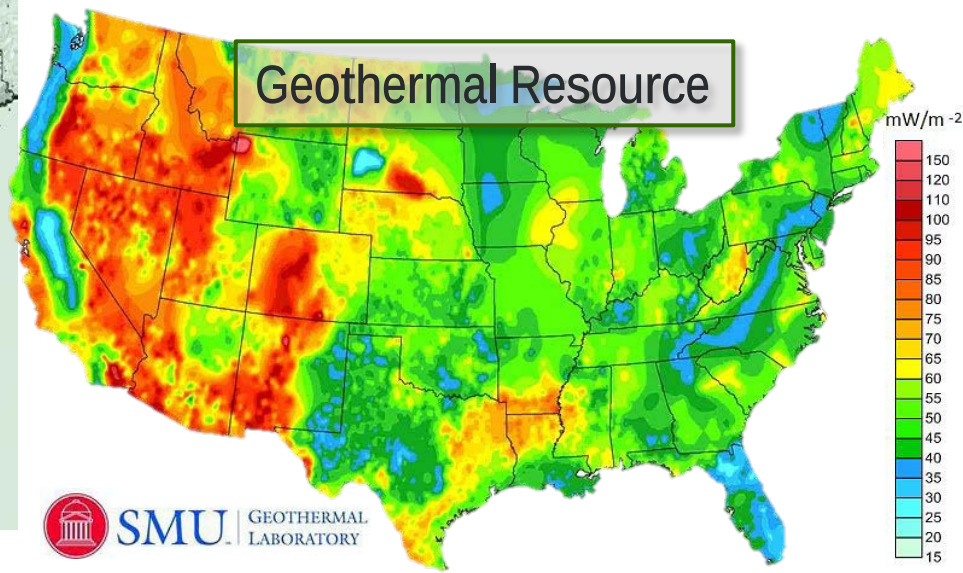
Brian J. Anderson, PI

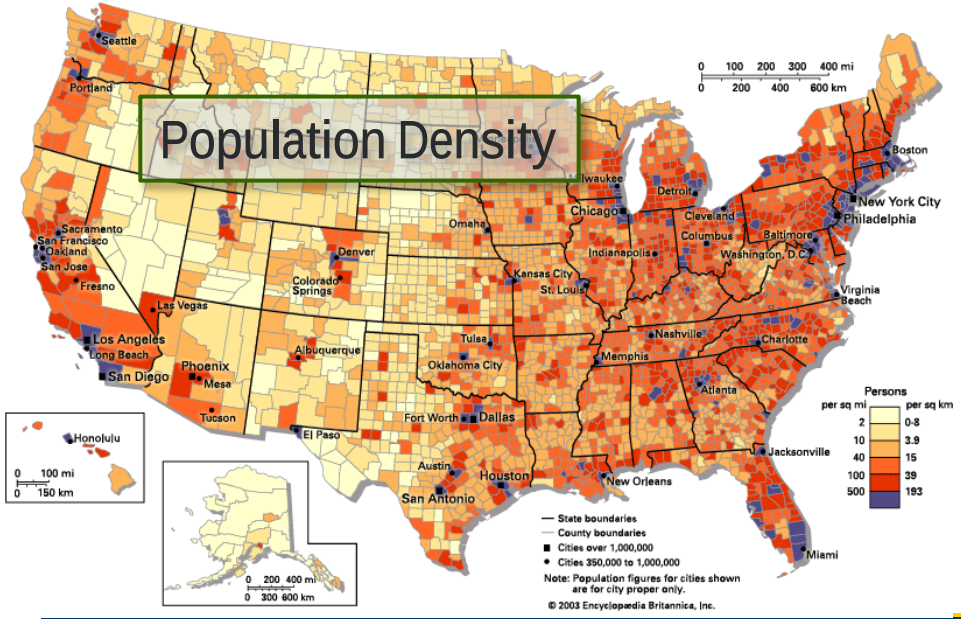
West Virginia University

Analysis, Data System and Education

Scientific/Technical Approach



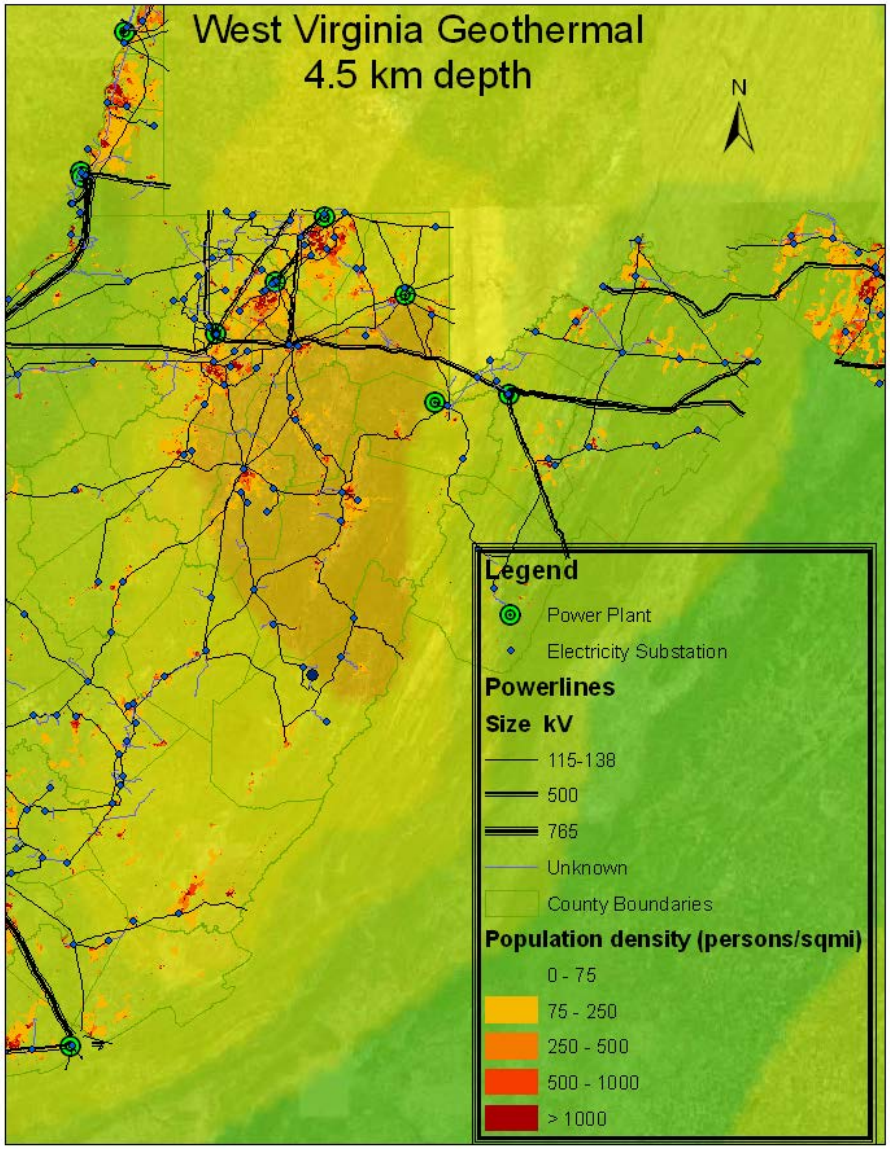




- **National Supply Curve**
  - Cost of supplied thermal energy is a function of:
    - Climate (degree days heating/cooling are utilized)
    - Geothermal Resource (drilling cost to temperature at depth)
    - Population density (demand profiles, piping costs)

Potential for direct-use geothermal in WV

- **Design of a geothermal well system to provide WVU with process steam**
  - WVU uses steam year-round to provide heating and cooling needs
  - Steam provided by Morgantown Energy Associates



Direct Use Geothermal

- **Geothermal energy can provide a stable, environmentally-friendly, and renewable, baseload energy supply**
- **Including heating and AC in industrial sector, it is safe to say 25% of total energy is used for such low temperature end-use**
  - geothermal energy can satisfy this end-use.

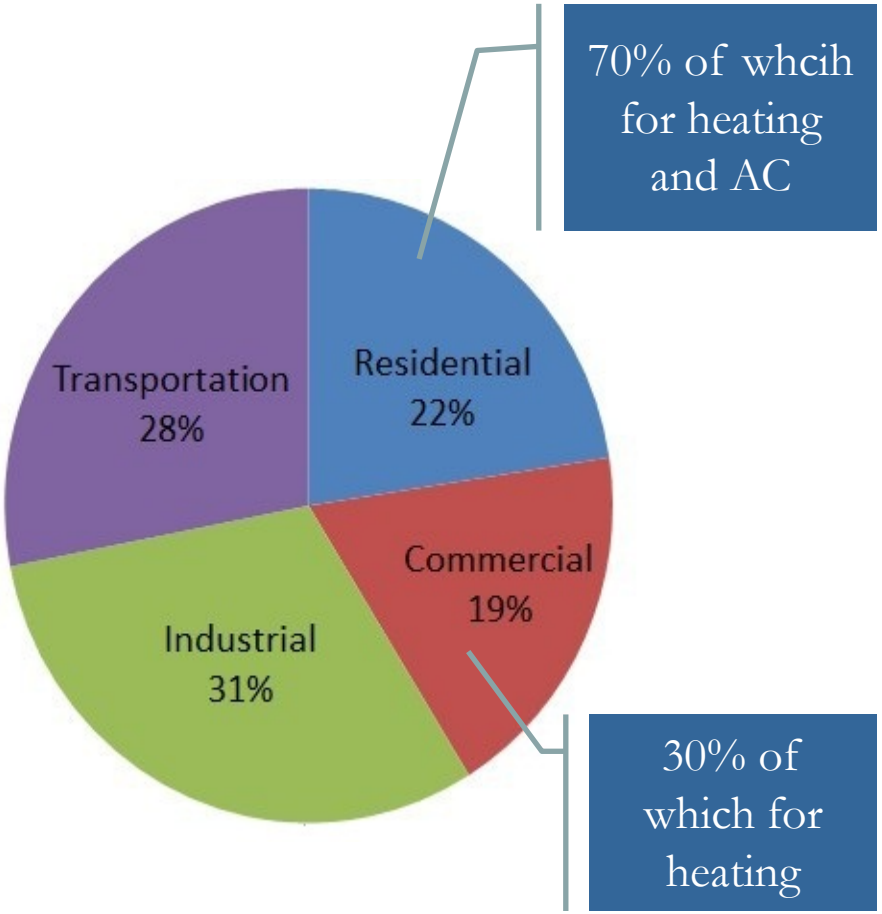
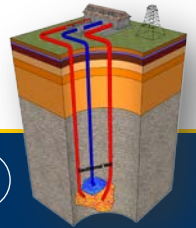
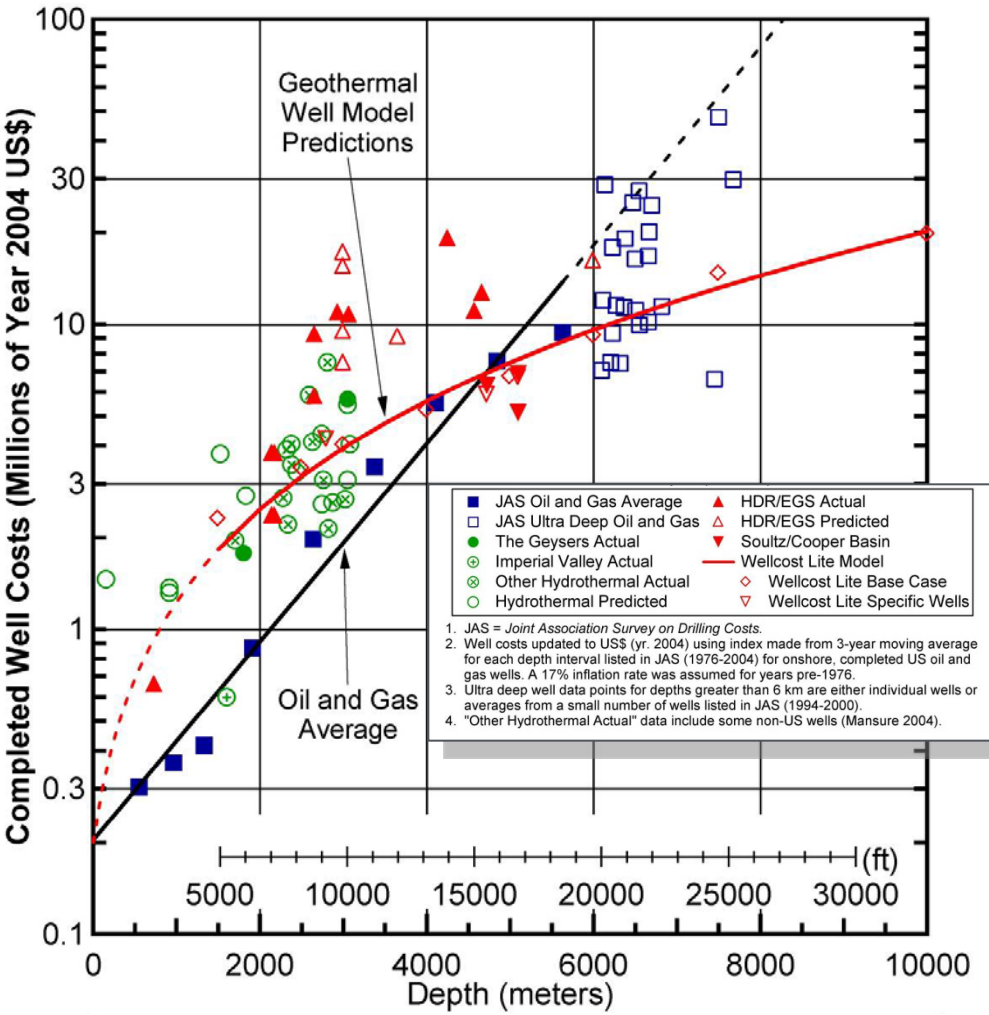


Figure 1: US Energy consumption scenario[EIA, 2011]
"Energy consumption estimates by sector, 1949-2010," U.S. EIA, 2011



Economic Advantage of Direct-Use for Low-*T* Geothermal

- Direct-use geothermal is able to capitalize on low-T resource
  - T = 110, 130, 150° C at
    2.5, 3.0, 3.5 km (40° C/km)
    5.0, 6.0, 7.0 km (20° C/km)
- Assuming \$300/kW$_{th}$ for heat exchangers and piping
- Doublets (1 injector, 1 producer)
  - 2004 US\$ and 2·(2004 US\$)
  - 500 m separation
  - 7-inch diameter
- Debt/equity rates
  - 5%, 10%, 15%
  - 20-year project life
- Assume 80 kg/s in producer



Economic Advantage of Direct-Use for Low-*T* Geothermal

40° C/km Geothermal Gradient

- T = 110, 130, 150° C at 2.5, 3.0, 3.5 km
- Total costs include redrilling the reservoir after temperature decline

- 2004 US$ Drilling Costs/well
  - $4.1, $4.8, $5.5 million
- 2x2004 US$ Drilling Costs/well
  - $8.1, $9.6, $11 million

Electricity Production (¢/kWh)

	T (°C)	5%	10%	15%
2004 Drilling Costs	150	13	21	29
	130	24	40	55
	110	99	159	217
2X2004 Drilling Costs	T (°C)	5%	10%	15%
	150	18	31	42
	130	34	57	79
	110	135	228	315

District Heating ($/MMBtu)

	T (°C)	5%	10%	15%
2004 Drilling Costs	150	1.90	2.68	3.55
	130	2.12	2.93	3.85
	110	2.46	3.33	4.32
2X2004 Drilling Costs	T (°C)	5%	10%	15%
	150	2.75	4.06	5.54
	130	3.03	4.41	5.97
	110	3.45	4.95	6.64

WVU Case Study Background

Health Sciences

- Has its own heating system.

The downtown campus

- Mostly uses steam through the buildings directly. It won't be economic to replace the steam system by geothermal water.

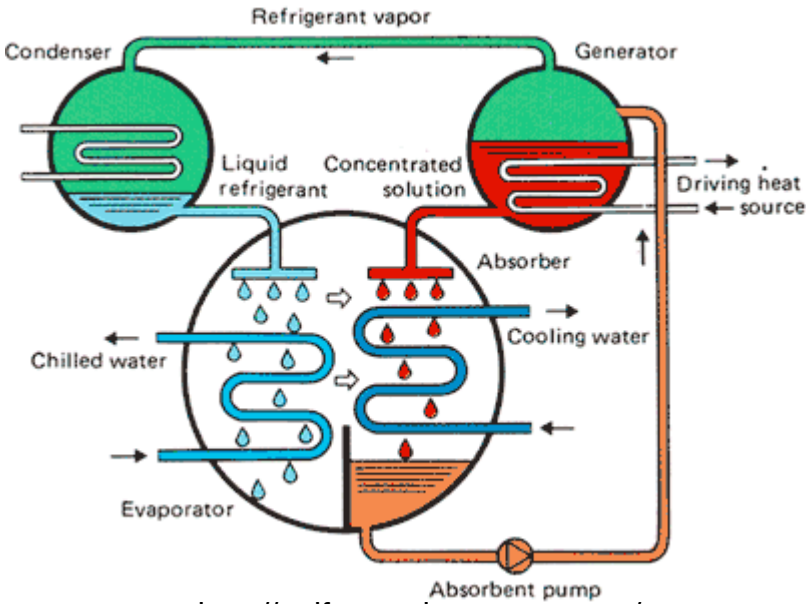
The Evansdale campus

- Only engineering campus is considered at this time since it uses a steam/water heat exchanger system.

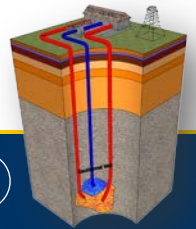
A 30,000-student campus with steam for *both* heating in the winter and steam for a distributed system of absorption chillers for cooling in the summer. Existing pipeline system is large enough to deliver hot water instead of steam.

Modeling Approach

- Convert current steam heating to geothermal water heating, simulated by Aspen Plus.
- Single phase H_2O/LiBr absorption chiller system, simulated by Aspen Plus.
- An energy and economic evaluations were performed for a feasibility analysis.



http://gulfcoastcleanenergy.org/



Aspen Plus Model of Heating System

Pipeline

- length, inner diameter, and distribution schematic provided by WVU Facility Management [WVU, 2011]

Heat exchanger

- no pressure drop, heat duty based on heat load by each building

Stream splitter

- no pressure drop, splitting fraction based on the ratio of the downstream building heat load and the upstream heat load

The main stream is initially set as 74 kg/s at 140° C and 58 psi. The model shows such stream can satisfy each building's heat load.

Aspen Plus Model of Absorption Chillers

- The total cooling load should be around 9,935 kW_{th} including the current absorption chillers in the Evansdale campus and the new absorption chillers proposed for seven more new buildings in the next few years.
- Assume: 1) Pressure change only occurs in pump and valves, 2) The pump efficiency is 100%.
- To provide 9,935 kW_{th} of total cooling load from the evaporator, the heat duty of the heat exchanger H2 would need to be 13,550 kW_{th}, requiring 51 kg/s of geothermal hot water at 140°C.

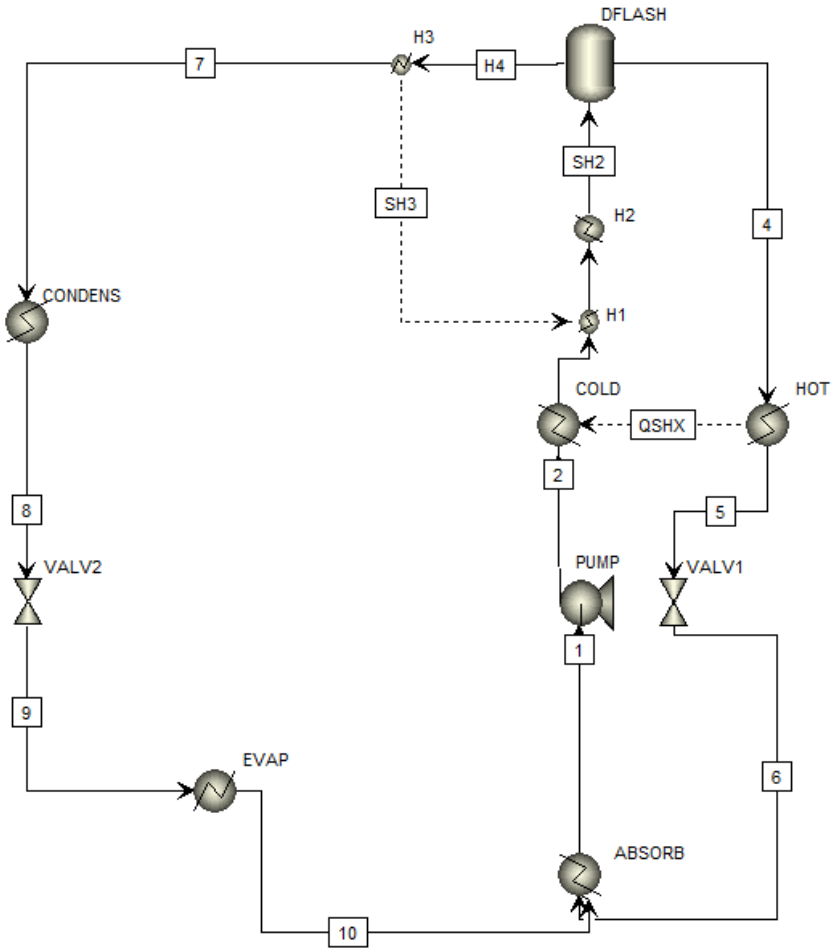
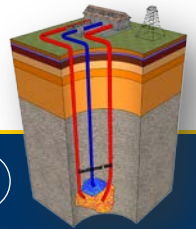


Figure 4: Aspen Plus Model of Single-Effect Absorption Chiller [Somers et al., 2011]



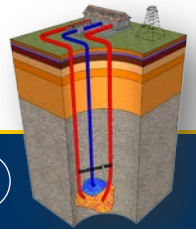
Economic Evaluation

- **Manufacturing cost on the whole project [Turton et al., 2009].**

Table 3: Factors Affecting Manufacturing Cost

Factor	Description
Direct Cost	
Operating Labor	Short as C_{oL}, one engineer is assumed here, averagely $70,000/year.
Direct Supervisory	Cost of administrative or support personnel, about $0.18C_{oL}$
Maintenance & Repair	About 0.06FCI*
Operating Supplies	Cost of daily operation excluding raw material, about 0.009FCI*
Fixed Cost	
Depreciation	Legal operating costs for tax purposes, about 0.1 FCI*
Local Tax and Insurance	About 0.032 FCI*
Factory Expenses	Payroll service, accounting, etc. About $0.708\ C_{oL}$ +0.036 FCI*
General Expenses	
Administration Costs	About $0.177\ C_{oL}$ +0.009 FCI*
Total	$2.065\ C_{oL}$ +0.246FCI*

**FCI: Fixed Capital Investment on plant-side, or the total direct cost.*



WVU Case Study

- **AspenPlus models of the heating distribution system and absorption chilling system constructed and analyzed.**

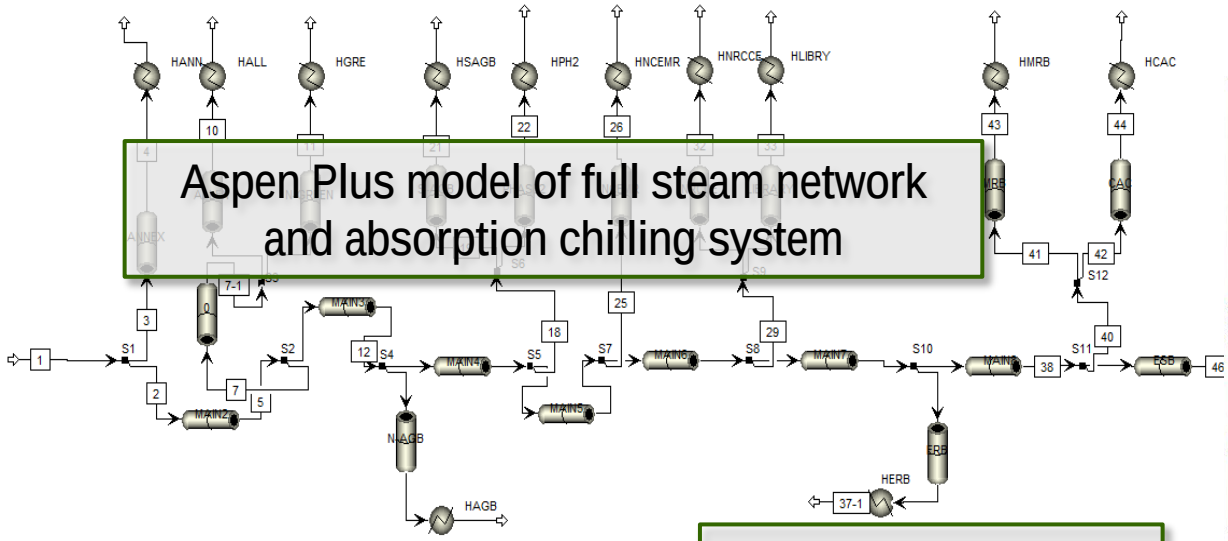
He, X., Anderson, B.J., "Low-Temperature Geothermal Resources for District Heating: An Energy-Economic Model of West Virginia University Case Study," SGW, 2012, SGP-TR-194

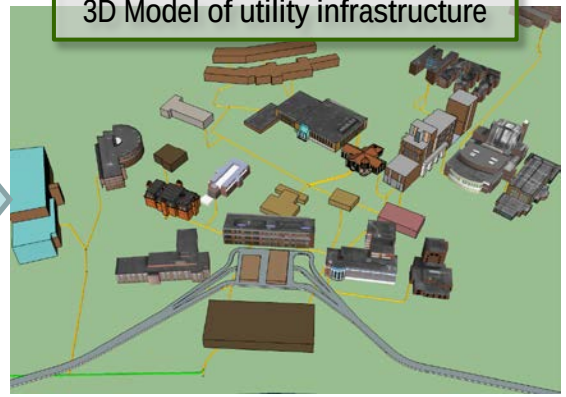
Case	Heating (MW_{th})	Cooling (MW_{th})	Levelized Energy Cost ($/MMBtu$_{th}$)
1	16.24	9.93	11.70~12.72
2	16.24	9.93	8.46~9.50
3	16.08	9.93	5.30~6.37

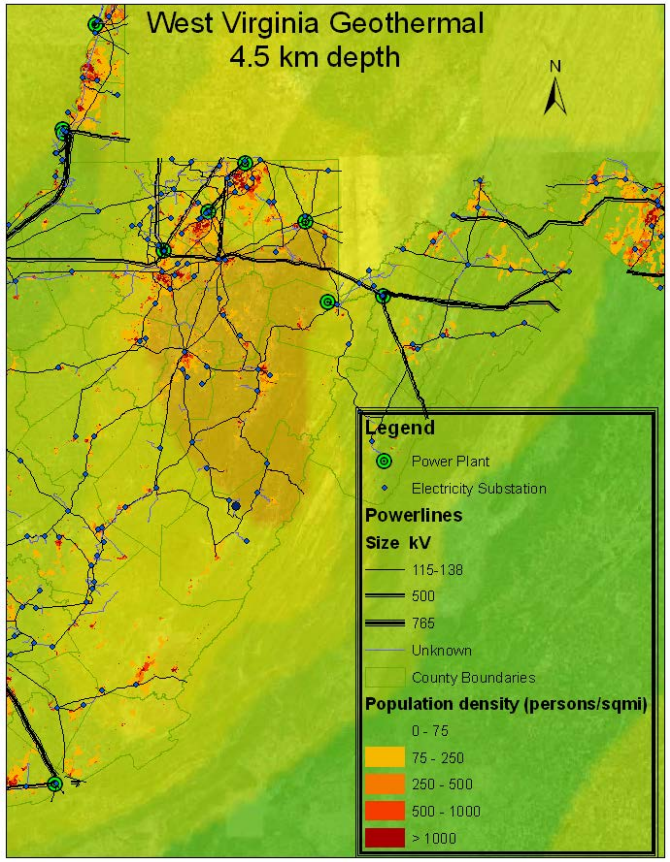
Case 1: Full costs, complete retrofit, no tax breaks

Case 2: Public entity bond rates, tax incentives

Case 3: Lower retrofit costs, using hot water not steam







Geothermal Gradient Factor

- **Data Analysis**

Original Data with depth, temperature, longitude, latitude

↓

Add into ArcMap
Create temperature maps at each depth

↓ ***for each map***

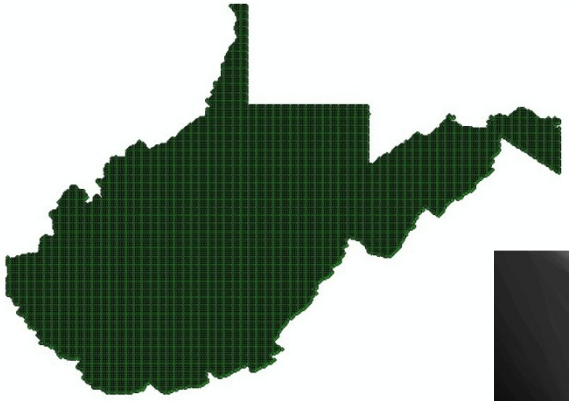
Data interpolation by IDW to create temperature surface

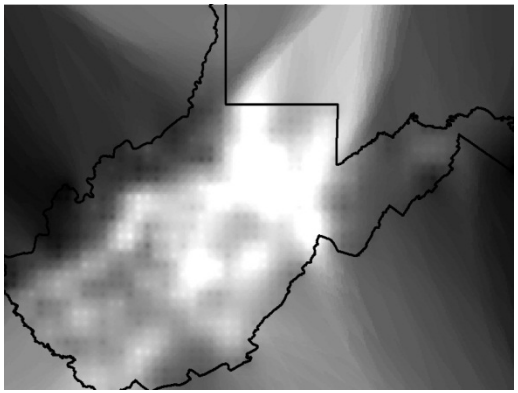
↓ ***for each map***

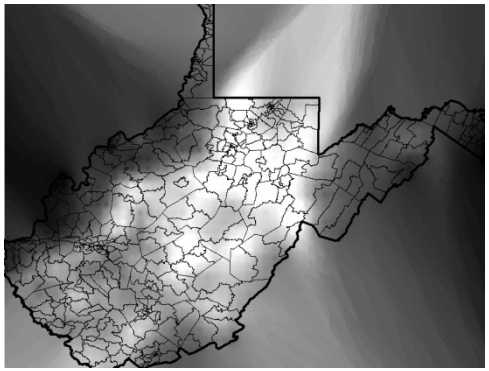
Get mean temperature at each census tract by zonal statistics as tables

↓

Calculate gradient for each census tract





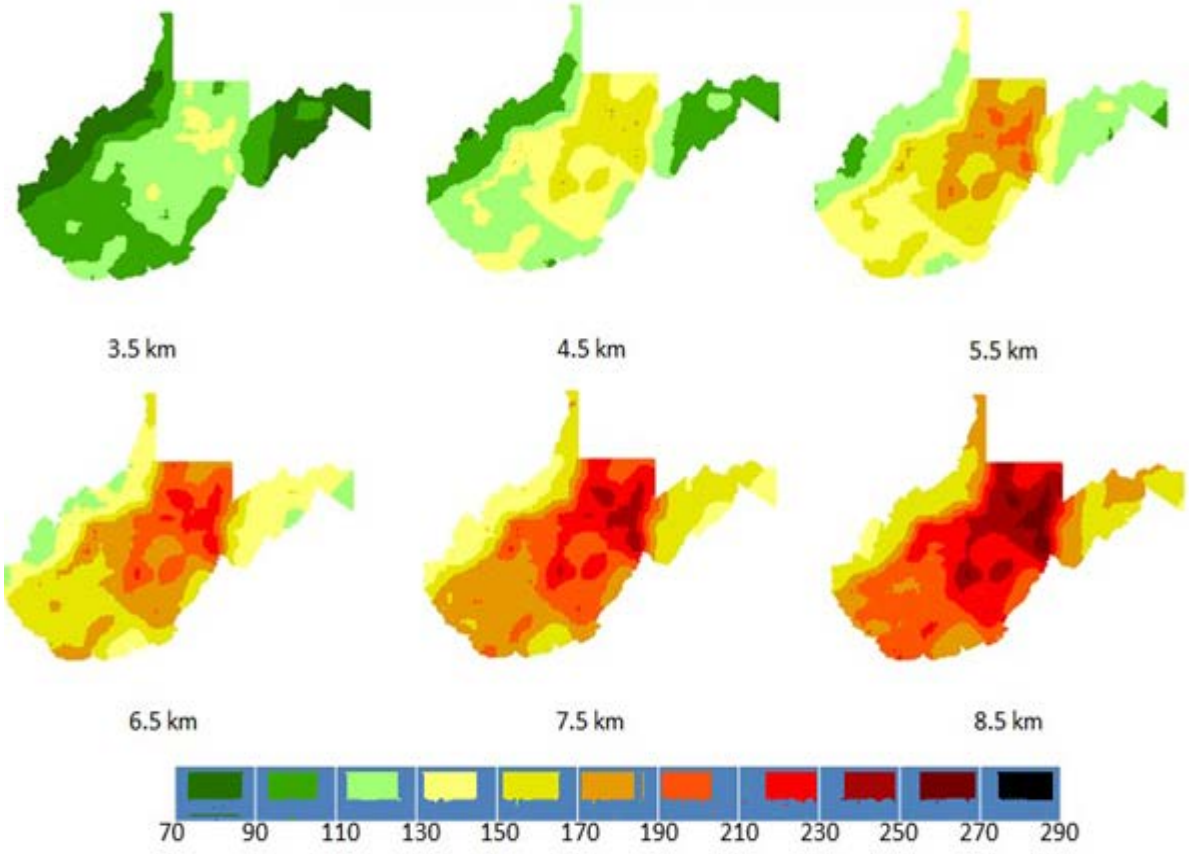


$$G = \frac{(T6-T3)+(T7-T4)+(T8-T5)}{3*3} \quad [°\ C/km]$$

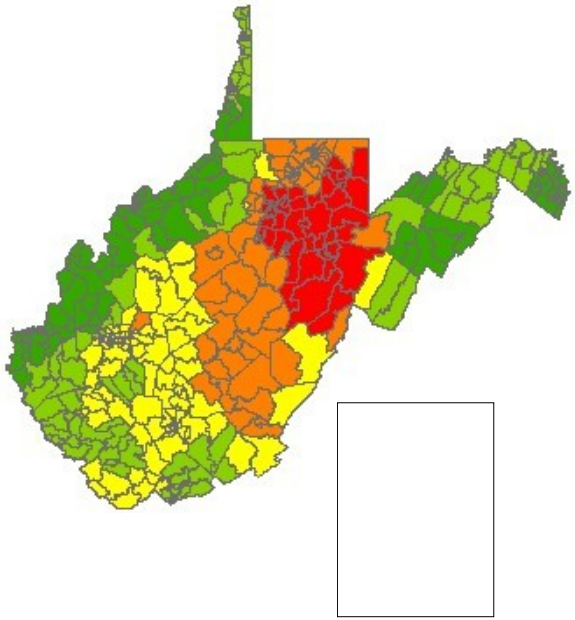
Figure 5: Data Analysis Procedure

Geothermal Gradient Factor

- **Data Analysis Results**



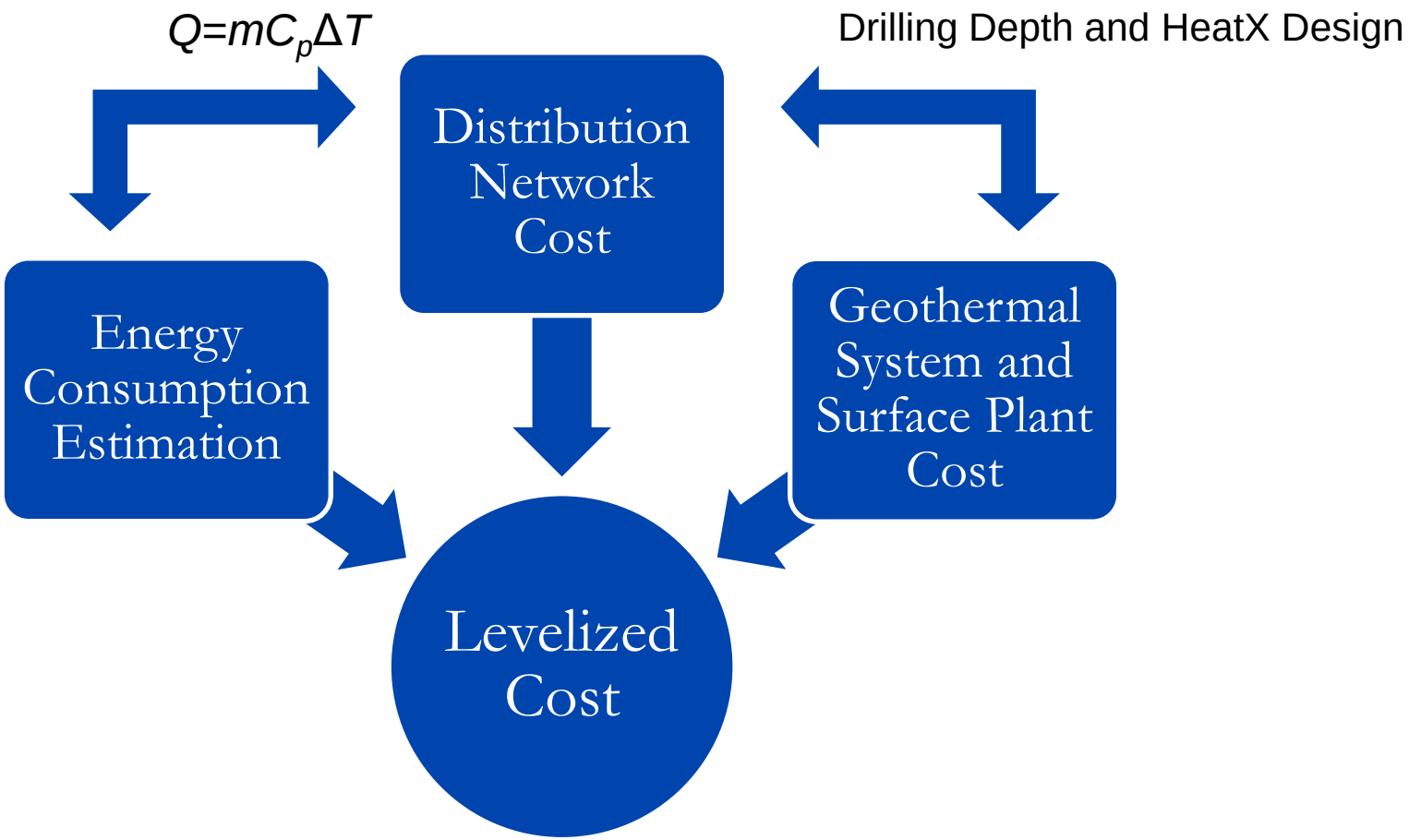
Geothermal Temperature at Depth at 3.5 km to 9.5 km



Geothermal Gradient Map

West Virginia University
Department of Chemical Engineering

Population Density Factor



WestVirginiaUniversity
Department of Chemical Engineering

Population Density Factor

Energy Consumption Estimation

- Average Household Usage: 220 MMBtu/year
- Average Household Size: 2.5 people
- Low-temperature End-use fraction: 0.68
- Household Number: base on WV census tract

Distribution Network Estimation

- Pipe length: $1.5AD(N^{1.04})$[1]
- $AD=\sqrt{0.1 * Area/N}$
- Electricity cost for pumping: $0.08/KWh
- Pipe sizing: base on mass flow rate

[1]: C. Yang, J.Ogden, "Determining the lowest-cost hydrogen delivery mode", Institute of Transportation Studies, University of California, Davis, 2006

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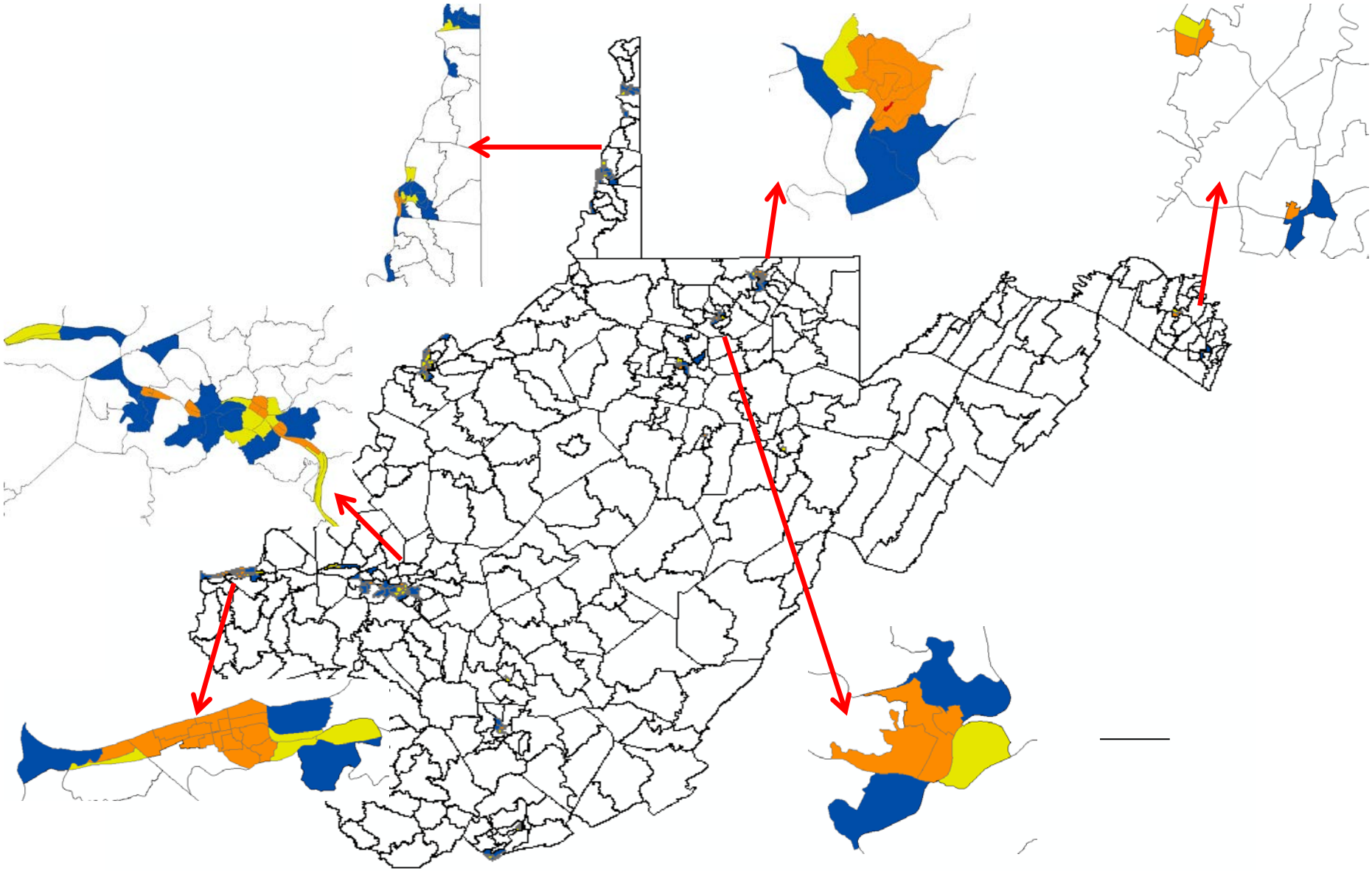
Department of Chemical Engineering



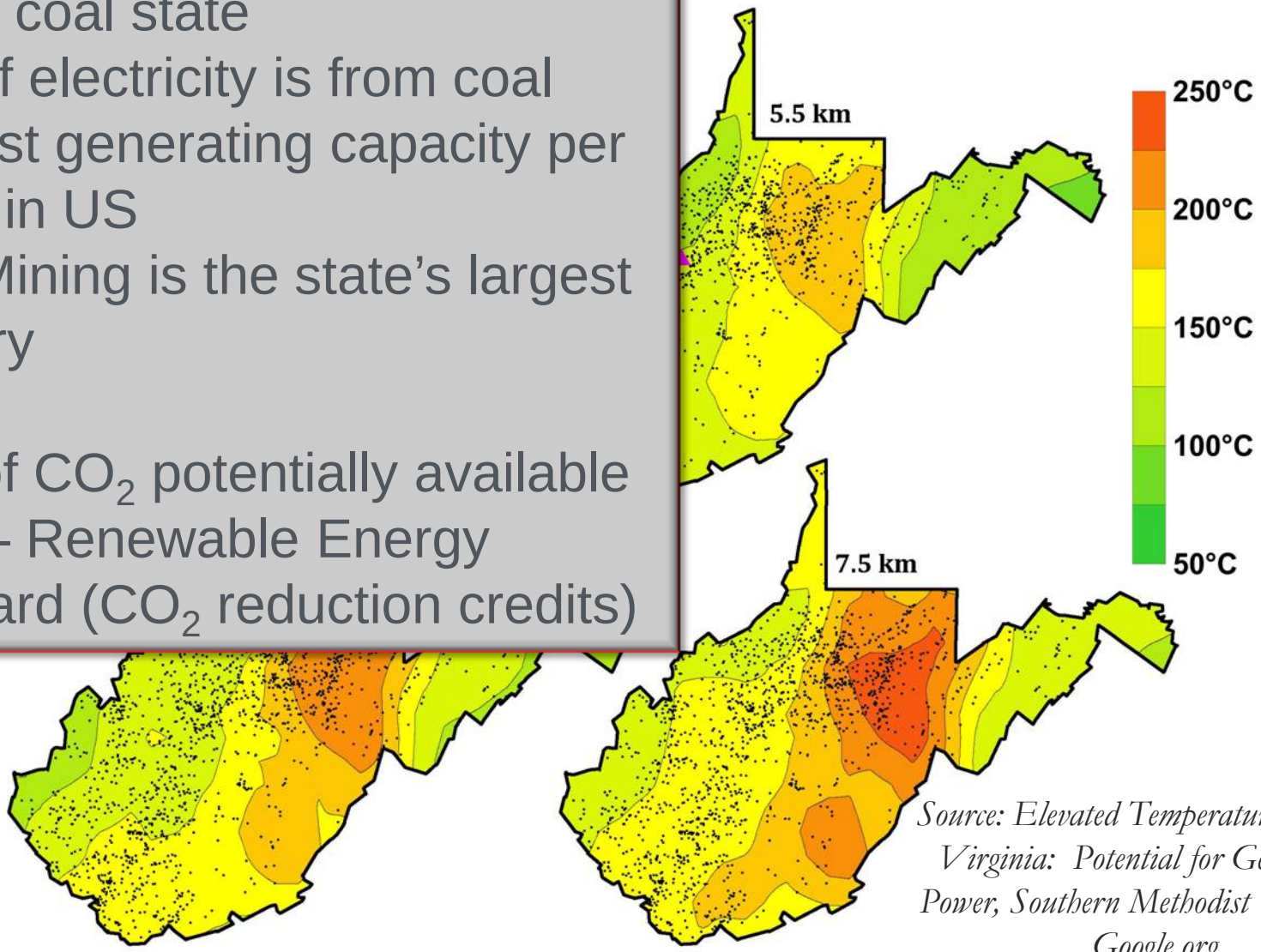
Direct Use Targets of Opportunity in West Virginia

WV Temperatures

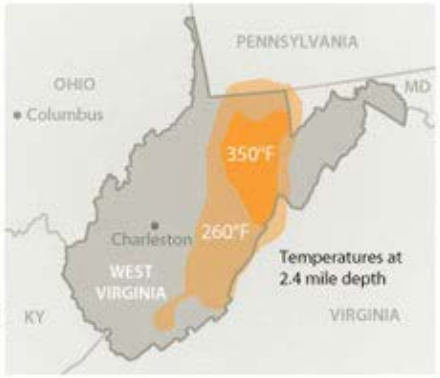
WV is a coal state

- 97% of electricity is from coal
- 3rd most generating capacity per capita in US
- Coal Mining is the state's largest industry

- Lot's of CO_2 potentially available
- 2009 – Renewable Energy Standard (CO_2 reduction credits)



Source: Elevated Temperatures in West Virginia: Potential for Geothermal Power, Southern Methodist University, Google.org



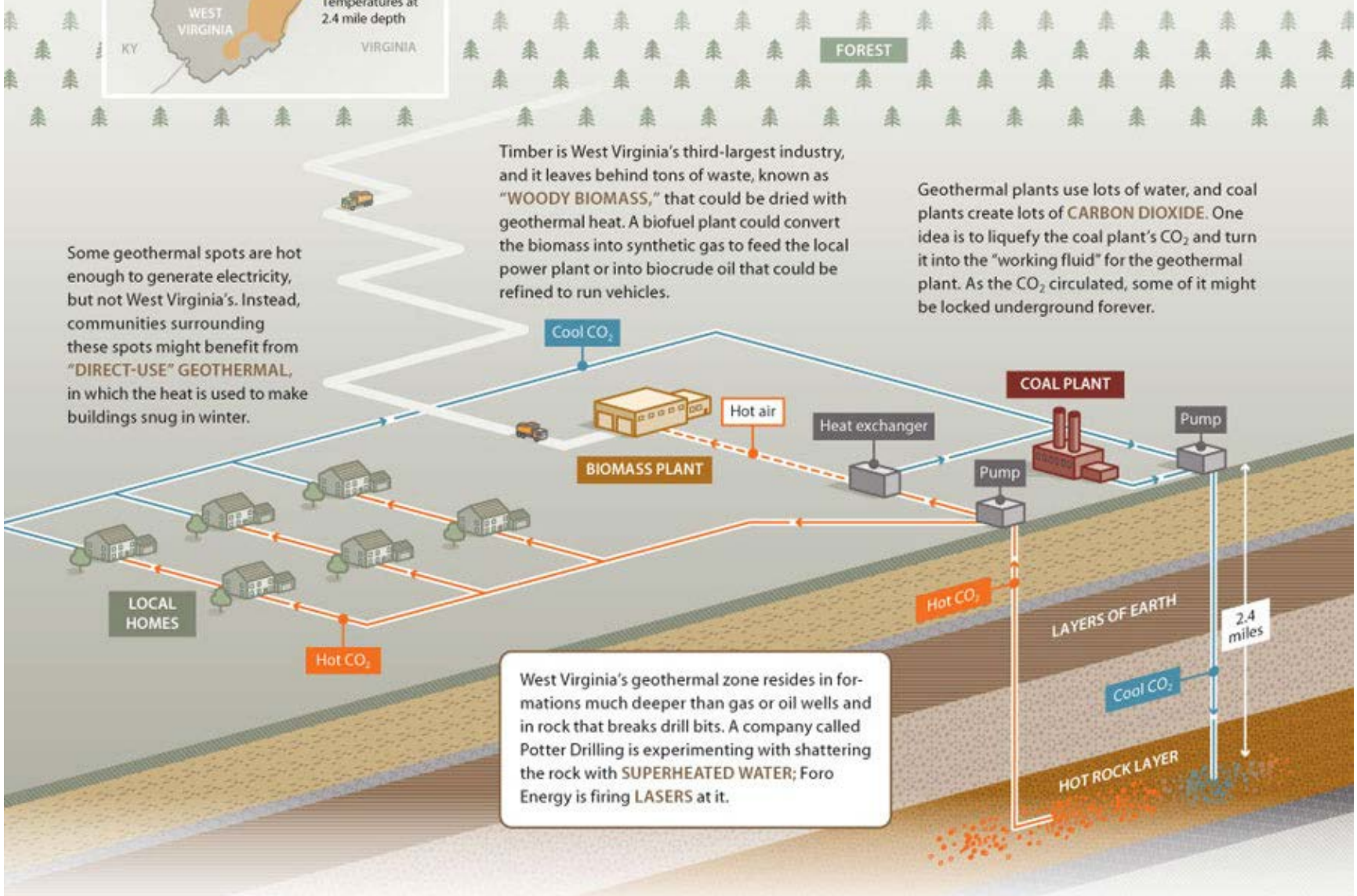
DEEP UNDER WEST VIRGINIA, below the infamous coal seams, is a mass of hot rock that could help power the state for millennia. Theoretically, the hot spot 2.4 miles under the Appalachian foothills could deliver 18,890 megawatts of energy—more than what West Virginia coal generates.

But getting to it is no easy feat. If engineers can find a way to affordably reach into West Virginia's geothermal pocket, then the trick can be repeated almost anywhere on the planet. Dig deep enough, and you find temperatures—though low by geothermal energy standards—high enough for power production. To eke every bit of warmth out of the 350-degree-Fahrenheit rocks, engineers could perform a renewable-energy double play: Tap the deep heat to warm buildings and also to dry out timber-industry waste for use as fuel.

Some geothermal spots are hot enough to generate electricity, but not West Virginia's. Instead, communities surrounding these spots might benefit from **"DIRECT-USE" GEOTHERMAL,** in which the heat is used to make buildings snug in winter.

Timber is West Virginia's third-largest industry, and it leaves behind tons of waste, known as **"WOODY BIOMASS,"** that could be dried with geothermal heat. A biofuel plant could convert the biomass into synthetic gas to feed the local power plant or into biocrude oil that could be refined to run vehicles.

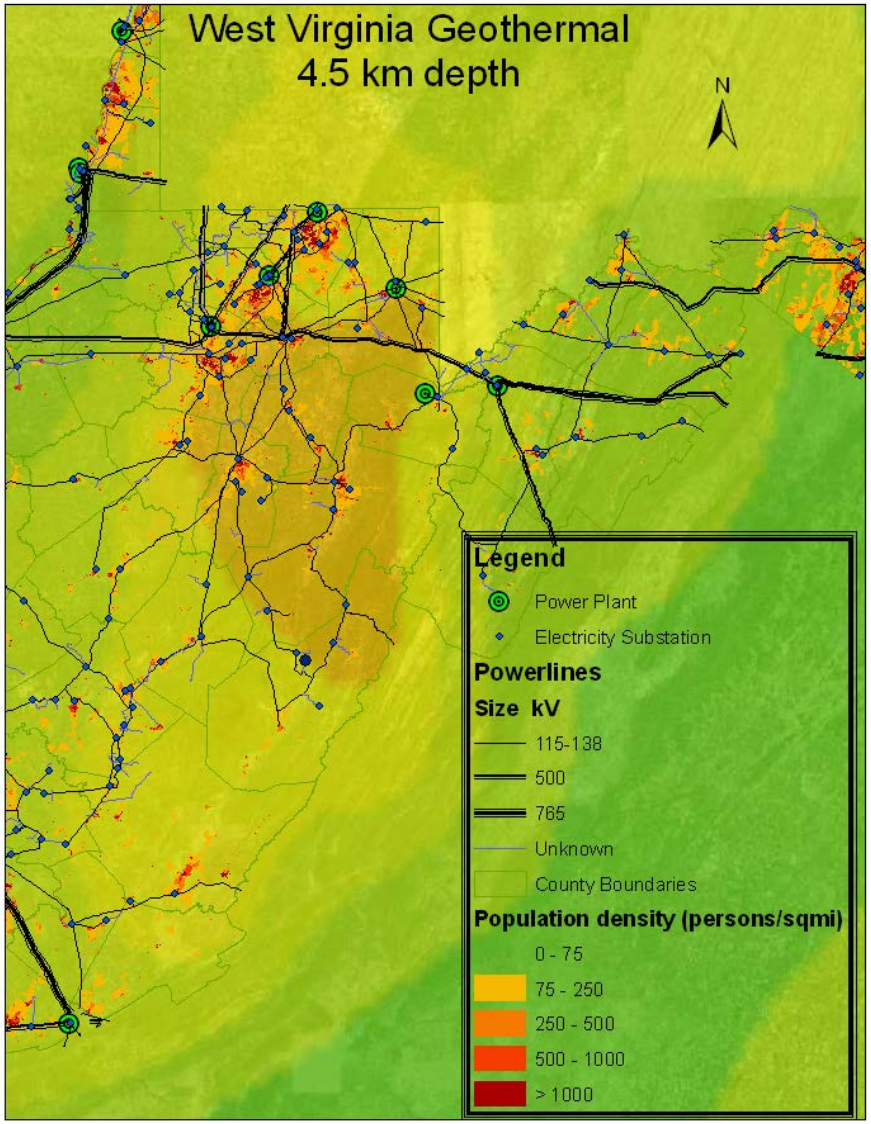
Geothermal plants use lots of water, and coal plants create lots of **CARBON DIOXIDE.** One idea is to liquefy the coal plant's CO_2 and turn it into the "working fluid" for the geothermal plant. As the CO_2 circulated, some of it might be locked underground forever.



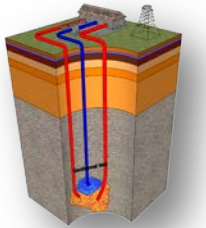
West Virginia's geothermal zone resides in formations much deeper than gas or oil wells and in rock that breaks drill bits. A company called Potter Drilling is experimenting with shattering the rock with **SUPERHEATED WATER;** Foro Energy is firing **LASERS** at it.

CO_2 Geothermal

- CO_2 stored in deep geothermal reservoirs may have many advantages over other alternatives for CO_2 sequestration, such as
  - shallow saline aquifers
  - coal seams
  - depleted oil and gas reservoirs
- The energy produced from the geothermal system will help offset the parasitic losses associated with CO_2 capture, separation, and pressurization requirements for both power generation and fuel processing operations



However, there are many fundamental science issues to be overcome



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Advanced Energy Initiative
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Questions?

Comments